AUGUST, 1960

Welding Journal

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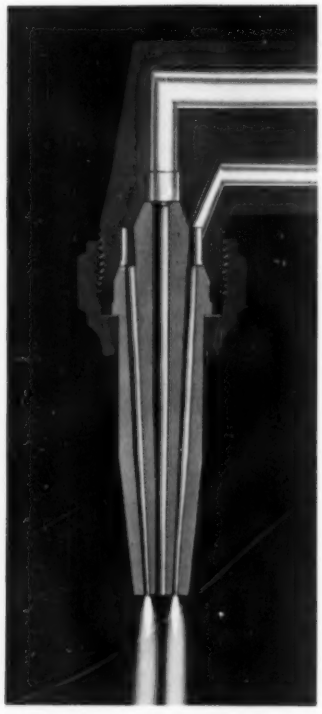
OFFICIAL PUBLICATION OF THE AMERICAN WELDING SOCIETY



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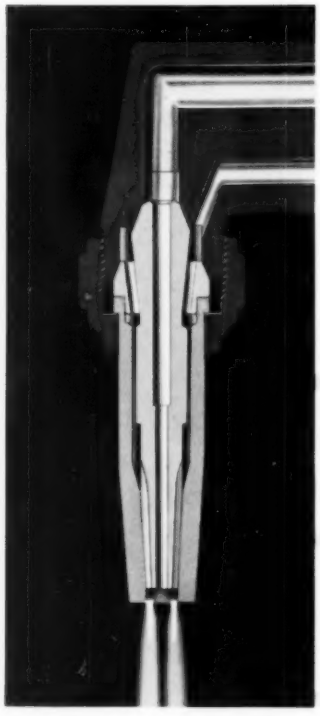

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PRESS-TIME NEWS ...about ...People ...Welding ...Products

Three internationally known delegates proffer a toast prior to the opening of business at the IIW Assembly. Left to right are: Rear Admiral E. H. Thiele, chairman of Ship Structure Committee; Walter Edstrom, president of IIW; Fernand Frenay, president of the Belgian Institute of Welding

IIW Elects Plummer at Liège Meeting

The 13th Annual Assembly of the International Institute of Welding was held at the Palais des Congrès, Liège, Belgium, from June 13 to 19, 1960, under the sponsorship of the Belgian Institute of Welding.

During the meeting, W. Edstrom (Sweden), president-elect, succeeded U. Guerrera (Italy) as president of the Institute and AWS National Secretary Fred L. Plummer became vice president of the Institute.

The principal business of the Assembly was the meetings of the 15 technical Commissions of the IIW. Each held four sessions at which many reports were discussed, some of which will be issued for publication.

In addition, three of the Commissions—Commission I (Gas Welding and Allied Processes), Commission V (Testing, Measurement and Control of Welds) and Commission X (Residual Stresses and Stress Relieving)—held colloquia, respectively, on the following themes: metal spraying; the inspection and testing of resinous materials (plastics); the influence of residual stresses on stability of welded structures and structural members. At each colloquium, a number of edited papers were presented by a Belgian reviewer and discussed. The Belgian delegation also organized a series of five lectures by lecturers from different countries on the subject of welding of very thick materials. The lectures were published in a special number of the *Revue Belge de la Soudure* issued on the occasion.

An International Exhibition of publications and photographs emanating from the member countries of the IIW was of much interest to those present.

The Assembly having been organized at the same time as the Liège International Fair, members were given an opportunity to visit the Fair, which included many stands of welding interest.

In the following week (June 20th–25th) the Belgian delegation organized two bus tours of industrial and historic interest in different parts of Belgium.

At the final session of the Governing Council in Liège, President M. F. Frenay of the Belgium Institute of Welding, in an impressive ceremony, delivered the flag of the IIW to President R. D. Thomas of the AMERICAN WELDING SOCIETY. It will be kept by the AWS until after the 1961 Assembly in New York at which time it will be delivered to representatives of Norway where the 1962 Assembly will be held.

The next Assembly of the IIW will be held in New York, Apr. 11–18, 1961.

Palais des Congrès on the bank of the river Meuse at Liège, Belgium, where the 13th Annual Assembly of the International Institute of Welding convened on June 13–19, 1960

A session of Commission XII "Special Arc Welding Processes" at the 13th Assembly of the IIW. At left are two of the members of the U. S. delegation, W. E. McKenzie of U. S. Naval Weapons Plant and AWS President R. D. Thomas, Jr., of Arcos Corp.

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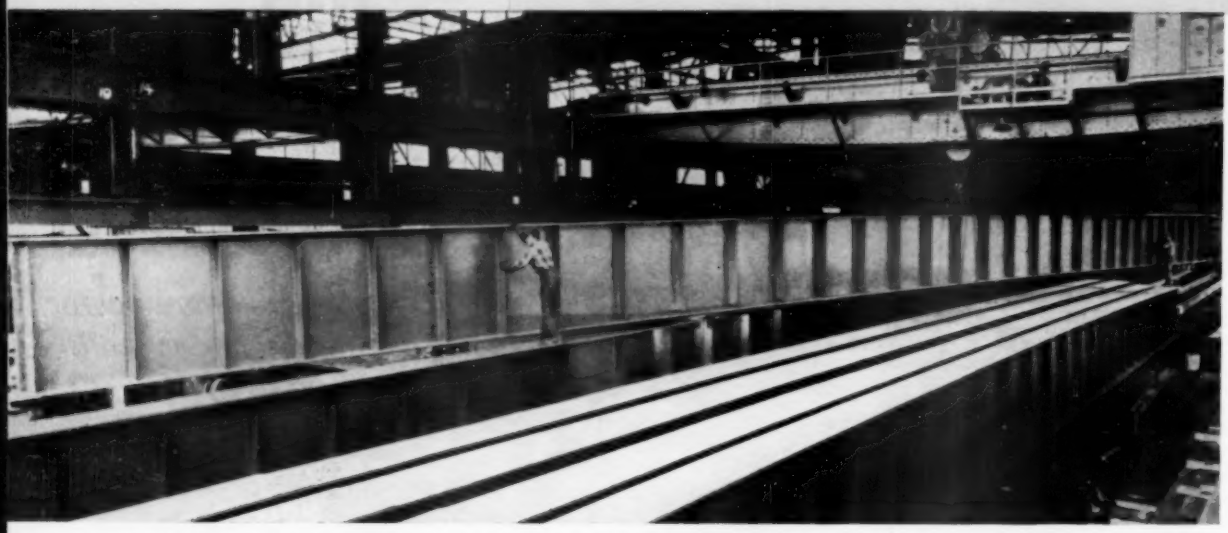
WELDING ZONES



Welded-plate girders, 131 ft long, were fabricated by Builders Structural Steel Co., Cleveland, Ohio. Web stiffeners are semiautomatic submerged-arc welded; flange-to-web welds are fully automatic. (Courtesy Jones & Laughlin Steel Corp.)

This 15-ton, 62-ft long, chrome-moly piping assembly has a $1^1/_2$ -in. wall thickness. Among the largest single pipe sections ever produced west of the Mississippi, the "hot reheat" header came from the shops of Midwest Piping Co., St. Louis, Mo.

The jungle-like area at Manalapan, Fla., is invaded in order to lay a 10-in. diam 4-D wrought-iron water line under Lake Worth. (Courtesy A. M. Byers Co., Pittsburgh, Pa.)

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WORLD-WIDE WELDING NEWS

By Gerard E. Claussen

BELGIUM

The Fall issue of the Belgian *Revue de la Soudure* describes the restoration of the welded rigid-frame Civil Engineering Institute of Liège University. The Institute was bombed in May 1944, 14 out of 25 frames being damaged. Most of the repair work involved splicing and stiffening. In one instance a part of the web of a column was replaced without removing the flanges. Much of the steel had a yield strength of 52,000 psi and required 490° F preheat.

Other articles in this issue described chromium boride hard-surfacing deposits in sugar-processing equipment, maintenance work on railway rolling stock, and an instrument for testing the flexibility of welding cables. The cable swings as a pendulum, and the extent to which the oscillations are damped in one minute is used as the measure of flexibility. Professor Soete's work on the brittle behavior of cracked plates at −22° F is summarized. In the absence of residual stress the brittle fractures occurred at a stress nearly equal to the elastic limit.

Strain-aging Test

The strain-aging test has been extended to weld metal in certain foreign specifications. An article in the Belgian magazine, *Arcos* (Nos. 141-2, 1959) presents strain-aging results on weld metal from three neutral-type electrodes, as-welded and after annealing at 1670° F, for 5, 10 and 15% strain. Three types of notch-impact specimen were used: Izod (V notch), Mesnager, and keyhole Charpy, the last two having notches 2- and 5-mm deep, respectively, and 2-mm diam. All were tested at 68° F. The results showed that annealing increased the effect of strain aging. The ratio of aged to unaged impact value at 10% strain was 0.18 for the Izod, 0.24 for the Mesnager and 0.26 for the keyhole specimens. Scatter in results was lower for the Izod than for the other. The conclusion was drawn that the Izod specimen should be used in preference to the Mesnager, which is now specified.

Dr. GERARD E. CLAUSSEN is associated with Arcrods Corporation, Sparrows Point, Md.

New Type Steel

About 4200 tons of the new L-D oxygen-converter steel was used in the all-welded 14,000 ton dry-cargo freighter *Linzertor*, according to the Belgian magazine *Acier, Stahl, Steel*, **24**, 1959. The steel averaged 0.16% C, 0.70% Mn, 0.26% Si, 0.025% P, 0.025% S and 0.05% Al. Bead-bend tests and explosive-bursting tests of cylinders welded from ship plate $^{3}/_{4}$ and $1^{1}/_{2}$ in. thick were passed successfully.

EAST GERMANY

The October 1959 issue of the East German welding magazine, *Schweisstechnik*, contains the following articles.

1. A summary of welding developments in Russia, including ultrasonic welding of plastics, an automatic arc welding machine for circumferential joints in pipes, and emphasis on increasing mechanization of production.

2. Welding developments in Rumania, including: (*a*) flash welding machine for rail joints; (*b*) nomograph for calculating temperature distribution in welding; (*c*) an electrode containing oil-stabilized ferrosilicon in the covering for welding cast iron; (*d*) a system of evaluating the arc-stabilizing properties of electrode-covering constituents by measuring the voltage drop in unit length of arc column, (*e*) a method of flash welding without reversing, which reduces oxidation and is accomplished by supplementary circuit to control the beginning of upset.

3. Planned expansion of welding in East Germany is expected to bring the annual production of weld metal from 17,843 tons in 1958 to 31,000 tons in 1965. The number of operator-years required to deposit a ton of weld metal (2200 lb) is 1.19 for arc welding, 13.4 for field gas welding, $2^{1}/_{2}$ to 4 for shop gas welding and 0.2 for automatic welding. In 1960, 5600 tons of submerged-arc wire and 8000 tons of flux will be required. In 1960, 800 tons of CO_2 wire will be required and 600 tons of CO_2.

4. The design of welded stock-piling bridges in brown coal mines involves the relation between length and weight, which is worked out in this article.

5. Rectifier production in East Germany will be accelerated because they require less copper and dynamo sheet than transformers and motor generators.

6. An oscillating head is used for surfacing the chain links of brown-coal-mining machinery. The speed of oscillation (pendulum action) is 150 ipm, while the forward travel speed is 25 ipm. From 15 to 20 lb of $^{1}/_{8}$-in. electrode (2% Mn) is deposited per hour, requiring 10 to 15 lb of flux.

7. Excess oxygen or acetylene was found to have no effect on the maximum hardness of gas-welded cast iron. The rate of cooling was the important factor.

RUSSIA

The September 1959 issue of the Russian magazine *Svarachnoe Proizvodstvo* contains the following articles:

1. The heat output of a plasma-jet torch with tungsten or carbon

NO. 8 OF A SERIES

"How to Design Welded Aluminum Structures"

Alcoa Tests Determine Fatigue Strength of Aluminum Alloy Weldments

Mr. Harry N. Hill, *Engineering Design Division Chief, Alcoa Research Laboratories, Aluminum Company of America, reports findings presented at the 1959 annual meeting of the American Society of Civil Engineers.*

In previous articles in this series, we have talked about the behavior of aluminum alloy weldments under a single load application. We have seen how the yield strength, tensile strength and compressive strength are influenced by the location and orientation of the weld—that is, by the design.

Design and configuration are even more important when a weldment must withstand many repetitions of loading without fracture. Fatigue failures have a habit of seeking out local regions of high stress. Frequently, these regions are not suspected.

An extensive fatigue testing program is being conducted at Alcoa Research Laboratories to evaluate the effect of various joint configurations on fatigue strength. Two general conclusions can be drawn from results of tests to date:

1. *The configuration of a welded joint has much greater influence on its fatigue strength than does the alloy of which it is made.*

2. *Fatigue strength is seriously impaired by abrupt changes in section and eccentricities that produce local bending.*

Figure 1 shows the results of fatigue tests of transverse butt welds in a high-strength aluminum-magnesium alloy. In these tests the stress in a cycle varied from zero to a maximum tension and back to zero. Even though the weld beads were reasonably smooth, the fatigue strength was materially improved by dressing the weld bead smooth with the surface of the plate.

More frequently than not, service loads consist of a fluctuating "live" load superimposed on a static "dead" load. In such cases the minimum stress in the cycle is something greater than zero. Fatigue strength for this kind of repeated loading is increased, as shown in Figure 2.

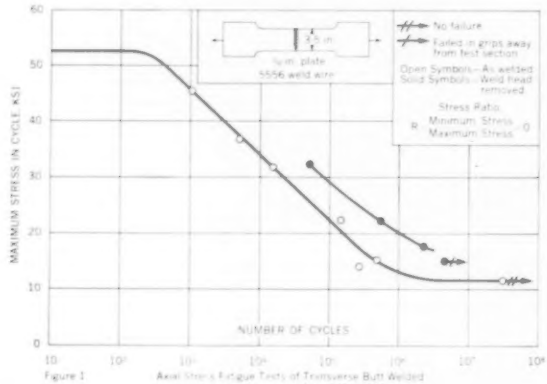
MAXIMUM STRESS IN CYCLE, KSI
NUMBER OF CYCLES
No failure
Failed in grips away from test section
Open Symbols—As welded
Solid Symbols—Weld head removed
Stress Ratio
R = Minimum Stress / Maximum Stress
5556 weld wire

Figure 1 Axial Stress Fatigue Tests of Transverse Butt Welded Joints in Aluminum Alloy 5456-H321

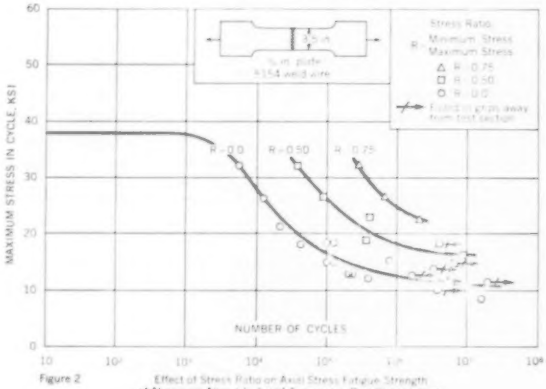

Figure 2 Effect of Stress Ratio on Axial Stress Fatigue Strength of Aluminum Alloy 5154-H34 Transverse Butt Welded Joints

This article concludes the series. We hope the material presented has been helpful to those concerned with designing welded aluminum alloy structures. Much research work still remains to be done, so the program at Alcoa Research Laboratories will continue in the future.

For top-quality aluminum welding products such as consumable electrodes, welding and brazing rods and fluxes, and solder and soldering fluxes, contact your nearest Alcoa sales office. For more complete information on "Designing Welded Aluminum Structures," write Aluminum Company of America, 1762-H Alcoa Building, Pittsburgh 19, Pa.

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electrode and argon or argon-helium atmosphere was plotted for currents up to 90 amp and gas flows up to 30 cfh. A survey of the heat distribution at various levels from the torch showed that, as the temperature dropped with distance from the torch, the heat output underwent sharp increases and decreases associated with deionization and recombination of atoms. The plasma has been applied to the welding of thin refractory metals.

2. Research on the heat treatment of 12% Cr steels before and after welding showed that addition of Mo, W and V lowered the sensitivity to grain coarsening and cracking in the heat-affected zone. Reeve cracking test results on 1-in. plates of steel containing 0.13% C, 0.28% Si, 0.59% Mn, 12.33% Cr, 0.60% Mo, 0.96% W, 0.23% V were satisfactory, if the preheat was 390° F. A strength of 20,000 psi at 10,000 hr was exhibited by this steel heat treated after welding to a tensile strength of 93,000 psi.

3. Weld metal containing 0.09% C, 0.43% Si, 3.26% Mn, 17.15% Cr, 8.75% Ni, 0.66% Mo, 0.65% W, 0.66% V, 0.34% Cb, 0.015% P, after heat treatment at 1490° F, had a strength of 31,000 psi at 100,000 hr at 1110° F. The weld contained $3\frac{1}{2}$% ferrite and was used for turbine motors.

4. The elimination of ferrite from austenite-ferrite high-temperature alloys such as Type 347 by annealing at 1470° F occurred most rapidly in forgings, less rapidly in weld metal and very slowly in large castings. Ferrite is desirable to prevent cracking during welding, is undesirable for high-temperature strength and is eliminated by annealing after welding.

5. Condenser-discharge welding was used to join thin-walled tubing of Type 304 stainless steel, $\frac{3}{8}$ to $\frac{5}{8}$ in. OD, 0.012 to 0.024-in. wall. The welds had good corrosion resistance in 55% HNO_3.

6. Short-time fatigue tests were made on spot-welded aluminum frames. Up to 20,000 applications of load were made. Spot-welded frames had practically the same strength as their riveted counterparts.

RUSSIA

The Russian automatic welding magazine *Avtomaticheskya Svarka*, for September 1959 contains the following articles:

1. The submerged-arc welding of fillet and butt joints in mild and low-alloy steels with three electrodes in tandem was accomplished with three-phase power. Fillets were welded in the flat position at 65 ipm and butt at 118 ipm. Cracks were encountered with over 0.13% carbon in the weld metal. Two electrode patterns were used. In one, the three electrodes were separated only $\frac{5}{8}$ to 3 in.; in the other, the lead electrode was 8 in. ahead. The electrodes generally were $\frac{3}{16}$ in. diam and were operated at currents up to 1800 amp.

2. Examination of electropolished and electrolytically etched specimens of submerged-arc weld metal (0.05% C) in an electron microscope revealed alpha veining in the ferrite. Pile up of dislocations at these impurity sites resulted in eventual cracking.

3. The fatigue strength of submerged-arc weld metal for mild steel was found to be increased by raising the manganese content of the electrode from 0.7 to 1.5% and by using AN60 flux (43.4% SiO_2, 39.0% MnO, 6.5% CaO, 6.2% CaF_2, 0.6% MgO) instead of the standard high-manganese flux.

4 The stress and deformation involved in unrolling rolls of plates $\frac{5}{32}$ to $\frac{3}{8}$ in. thick for field-erected oil storage tanks were found by calculation to be negligible.

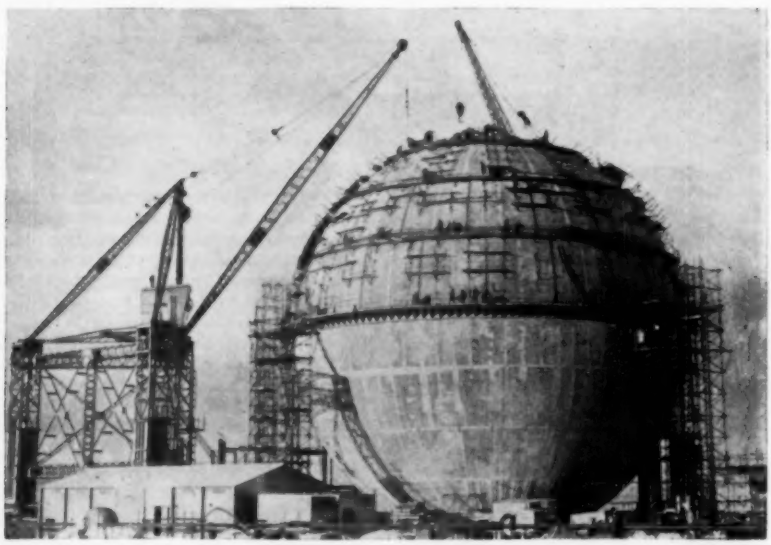
5. With straight fluoride flux it was impossible to secure good fusion of plate to weld metal in electroslag welding steel containing 0.08% C, 15% Cr, 9% Ni and $1\frac{1}{4}$% Al. Addition of silica or lime to the flux eliminated the lack of fusion. Tensile strengths up to 190,000 psi were attained in welds containing ferrite in steels of this type.

6. Static tensile tests were made at −76° F on welded tubular joints intersecting at 30, 60 and 90 deg. It was necessary to stiffen the 90-deg joint by inserting an inner tube to prevent collapse of the tube wall and consequent premature failure.

7. The change in longitudinal residual stress and distortion in submerged-arc welds in $\frac{5}{16}$-in. steel plates by preliminary application of tensile and compressive load was found to agree with calculations.

8. The three-electrode electroslag process was used to weld the girth seams of a 36-in. diam, $3\frac{1}{2}$-in. wall pressure vessel at a speed of 0.7 ipm. Means of starting and completing the welds are described, as well as the positioners that were required. The welded vessel was normalized at 1700° F.

UNITED KINGDOM



Sphere for the nuclear reactor at Dounray

WEST GERMANY

Vessel Failure

The September 1959 issue of *Schweissen und Schneiden* carried an article on a vessel failure. Examination of a welded low-alloy steel pressure vessel that exploded while carrying a liquid propane-butane mixture at 16° F revealed that fracture started in a rimmed steel stiffener which was welded to the tank. The crack started at a flame-cut area in the segregated core of the rimmed steel and was propagated by fatigue into the shell of the tank.

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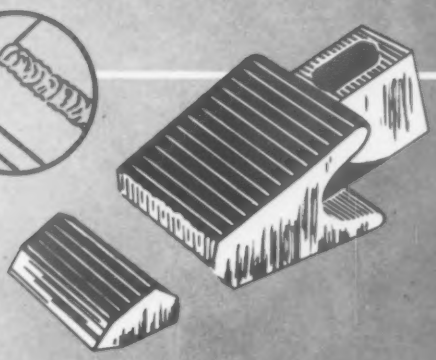

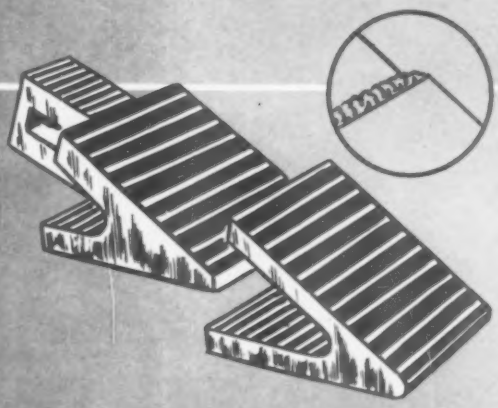

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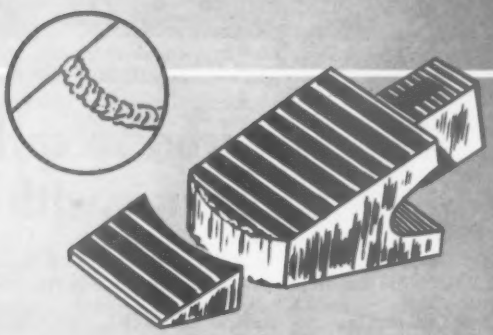

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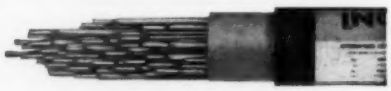

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Searching for Utopia

Utopia is defined as a state of social perfection, although most people have come to associate it with a search for an ideal. It is in searching for Utopia that one expects to find truth, and yet, truth has many aspects, depending on one's point of view. Such an aspect may be one's concept of weldability as regarded from the viewpoint of others.

In the field of metals joining, the concept of weldability and its evaluation has given rise to much argument. The metallist has a viewpoint and the engineer has one, too—but they are not quite the same, although both may be interested in the same ultimate objective. Only when the two get together and intelligently combine their viewpoints does a usable concept of weldability emerge.

Since this acceptable concept includes both ease of fabrication and serviceability, the complexity of its evaluation by any single-shot type of test becomes readily apparent. From an over-all viewpoint, the most thorough weldability test would be to fabricate a weldment and put it into service for an appraisal of its useful life. However, such procedure is wasteful, costly and gives no useful information prior to fabrication, all of which reduces its usefulness.

Test procedures are in use for which an effective correlation has been established between the test results and fabrication experience with a specific type of welding operation. However, this correlation does not pertain to weldment serviceability and such tests cannot be regarded as a weldability criterion since they do not give an over-all evaluation. The search for Utopia continues.

Is Utopia practicably attainable? The answer is emphatically *no*. Infinite variations are possible, not only in weldment design but also in service requirements. One test cannot cover them all. However, for a specific service and a specific weldment design, there may be developed a specific weldability test if a definite correlation is established between test results, fabrication experience and service performance. This is not quite Utopia but it is the closest approach to it that one may expect to make in a practical sense.

William L. Warner

TECHNICAL ADVISOR

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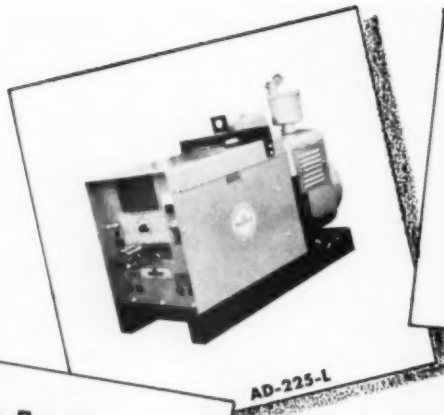

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Station for automatic welding of side stakes to side sheet, the latter being one continuous plate 58 ft 10½ in. long and 9 ft 6 in. wide. Manual touch-up gun is shown in foreground

Over 250 miles of welding by the gas metal-arc process are used in the

Assembly-Line Fabrication

of All-Welded Aluminum Covered-Hopper Cars

BY DANA V. WILCOX AND RONALD HUBBARD

FOREWORD. Development of the inert-gas metal-arc welding processes for aluminum, both manual and automatic, has opened up many new applications for the light metal. One of the larger and more interesting applications is in fabrication of all-welded aluminum covered-hopper cars.

Today the aluminum industry has the right combination for railroad-car construction. Plates and extruded shapes are available in sizes for economical car fabrication. Welding techniques have been developed so that fabrication in aluminum is faster and reduces total labor cost.

DANA V. WILCOX is Welding Engineer for Reynolds Metals Co. and RONALD HUBBARD is Welding Engineer for Magor Car Corp.

Paper to be presented at the AWS National Fall Meeting to be held in Pittsburgh, Pa., Sept. 26-29, 1960.

Southern Railway System ordered 455 aluminum 100-ton covered-hopper cars (steel center sills) from the Magor Car Corp., Clifton, N. J. Being lighter than steel, they will carry heavier payloads for greater profit. Since they need no painting for corrosion resistance, the maintenance saving and ultimate scrap value, plus increased payload, will offset the original higher cost. The rust-free, smooth aluminum will afford cleaner dumping; thus, reducing cleaning time when changing cargo.

Because of their size and the extensive use of aluminum, the new cars will cost more than conventional cars of the same type. But Southern Railway studies indicate that this added initial cost will be more than offset by the greater carrying capacity and lower tare weight.

Comparison figures of aluminum covered-hopper cars to steel covered-hopper cars are shown in Table 1.

Seventy-five of these cars are reported to be the world's largest covered-hopper cars. These are of 4713 cu ft capacity, have four hoppers and are designed to carry food products. One hundred and eighty are triple covered-hopper cars of 3818 cu ft capacity, designed for aplite, coating clays, feed, sodium chloride, alumina and similar bulk commodities. Two hundred are twin covered-hopper cars of 2600 cu ft capacity, designed primarily for dry cement.

Design

Full advantage has been taken in the design by employing six separate aluminum extruded shapes, both full-length and cut-to-size at the mill, along with large one-piece plates for sides, eliminating butt welds on smaller sheets. This greatly reduces fabrication time. The largest side sheets on quadruple hopper cars are 49-ft long by 9 ft-4 in. wide and are $^{5}/_{16}$-in. thick. More complete information on dimensions is given in Table 2.

Table 1—Comparison Figures on Covered-hopper Cars

	LAHT steel	Aluminum
Twin		
	Capacity: 2605 cu ft	Capacity: 2605 cu ft
	Weight: 54,400 lb	Weight: 43,600 lb (aluminum wt 10,979 lb)
		Length: 35 ft over strikers
Triple		
	Capacity: 3818 cu ft	Capacity: 3818 cu ft
	Weight: 63,200 lb	Weight: 50,100 lb (aluminum wt 15,600 lb)
		Length: 47 ft over strikers
Quadruple		
	Capacity: 4605 cu ft	Capacity: 4713 cu ft
	Weight: 72,500 lb	Weight: 56,400 lb (aluminum wt 19,391 lb)
		Length: 58 ft 10½ in. over strikers

NOTE: The above figures are based on low-alloy, high-tensile steel. If mild steel is used, an additional weight would be added to the steel cars.

Table 2—Dimensions of Hopper Cars (Track Limit 251,000 Lb Including Car)

	Twin hopper, 100 ton, 2600 cu ft	Triple hopper, 100 ton, 3818 cu ft	Quadruple hopper, 100 ton, 4713 cu ft
Height	14 ft 7 5/16 in.	14 ft 7 5/16 in.	14 ft 5 in.
Width (out)	10 ft 6 23/32 in.	10 ft 6 23/32 in.	10 ft 3 1/2 in.
Width (in)	9 ft 11 1/8 in.	9 ft 11 1/8 in.	9 ft 6 7/8 in.
Length (out)	35 ft 3 in.	47 ft	58 ft 10 1/2 in.
Length (in)	29 ft 3 in.	41 ft	57 ft 10 1/8 in.
Weight	43,600 lb	50,100 lb	56,400 lb
Weight (aluminum)	10,979 lb	15,600 lb	19,391 lb
Weld feet per car	2500 ft	3100 ft	3800 ft

Welding Process

The inert-gas-shielded metal-arc welding process, both manual and automatic, has been developed so that fabrication of the aluminum structure is economical. Due to high deposition rates, faster welding speeds in both manual and automatic processes are now practical.

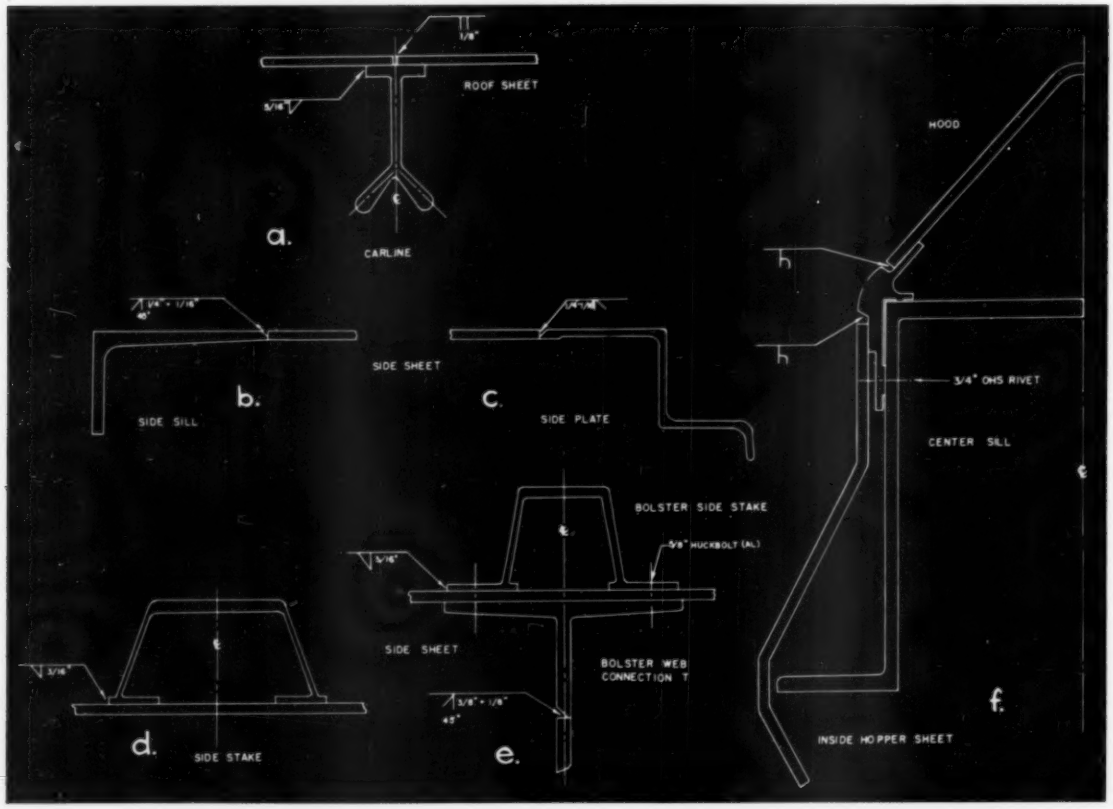
Table 3—Properties of Material Used

	Before welding	After welding
Ultimate tensile strength, psi	46,000	45,500
Yield, 2 in. gage, psi	33,000	26,000
Elongation, 2 in. gage, %	16	12
5083-H113 aluminum sheet and plate		
5083-H112 aluminum extrusions		

Materials

The aluminum covered-hopper cars are made of 5083-H113 alloy plate and sheet, varying from 3/16-in. thick for roof sheet to 5/8 in. thick for hopper and slope sheets. Inside hopper sheets are made of 5083–0 alloy because of severe forming requirements. The extrusions are 5083-H112 alloy of various special shapes, developed to simplify fabrication. The casting alloy is 356, both permanent mold and sand type castings. The welding wire is Type 5356 aluminum alloy, supplied to Military Specification MIL-16053-E, employing the zincate finish. A

Fig. 1—(a) Carline—extruded shape for roof support. Roof sheets 3/16 in. thick, butt welded into carline. (b) Side sill—extruded shape welded to side sheet without additional edge preparation. (c) Roof sill—extruded shape welded to side sheet. (d) Side stake—reinforcement for side of car. (e) Chute extrusion and bolster web connection showing edge preparation for butt weld. (f) Bolster stace—extrusion riveted to center sill with butt weld tying in inside hopper sheet and hood over center sill



total of 7,000,000 lb of aluminum sheet, plate and extrusions, 1,632,000 cu ft of argon gas and 68,000 lb of aluminum welding wire are required to produce over 250 miles of aluminum welding in the construction of the 455 aluminum covered-hopper cars.

Typical Properties

Listed in Table 3 are typical properties of base metal and typical properties of welded test material.

Special Extruded Shapes

Special extruded shapes were designed with edge preparation to obtain 100% penetration, employing temporary stainless-steel backing bars (see Fig. 1, a–f).

Aluminum-metal Preparation

All aluminum parts used in subassemblies after forming or cutting to size are cleaned by the hot-dip process. They are submerged in a diluted solution of phosphoric acid at 160° F for 1 to 3 min, rinsed in hot water and thoroughly dried, to remove grease, dirt and contaminated oxide.

The larger parts such as side sheets, side sills and slope sheets are wire brushed in the weld areas, and washed and rinsed by hand prior to final tacking or welding. The stainless-steel wire brushes, rotary type, 0.015 bristles, are periodically cleaned in a degreasing solution (caustic) and are rinsed and thoroughly dried as needed.

Fabrication

General

In the fabrication of the welded-aluminum covered-hopper cars, all welding, both automatic and manual, is performed with d-c reverse polarity, with the exception of the center sills and contained parts which are made of steel. The butt weld in center sill is made with the triple-electrode submerged-arc process employing two d-c arcs and one a-c arc. Flat-position welding is obtained through use of special fixtures.

All aluminum welding is done employing the consumable-electrode inert-gas-shielded metal-arc process under a shield of argon gas piped throughout the plant. Ten automatic and 70 manual guns, employing aluminum wire of $^3/_{64}$, $^1/_{16}$ and $^3/_{32}$ in. diam, both push and pull types, are used for manual welding.

The fabrication of welded-aluminum covered-hopper cars contains from 2500 lineal feet of welding for a twin to 3800 lineal feet for a quadruple. This creates the problem of shrinkage and distortion, particularly when the cars are built on an assembly line where each welding position is required to complete a predetermined amount of welding in an allotted time, controlled by the number of cars on the daily quota. Welding procedures had to keep pace with the production requirements of six twin, six triple or four quadruple covered-hopper cars per day. A successful compromise was to prefabricate as many parts as possible and to weld these into principal assemblies limited only by size.

Fig. 2—Center-sill underframe consisting of center sill, bolsters, end sills and center fillers

Fig. 3—"A" and "B" body bolsters and cross-ridge center-slope sheets

In construction of the twin, triple and quadruple aluminum covered-hopper cars, four principal assemblies were used.

Figure 2 shows the underframe consisting of these subassemblies; namely, the sill, bolsters, end sills and center fillers.

Figure 3 shows *A* and *B* end body bolsters consisting of webs, gussets and floor sheets, and center partition consisting of cross-ridge and center-slope sheets.

Fig. 4—Prefabricated sides ready for assembly line

Fig. 5—Over-all view of subassembly section showing traveling manipulators and subassembly jigs

Fig. 6—Automatic welding of floor-sheet gusset assemblies

Fig. 7—Manual welding of gusset assembly

Figure 4 shows sides consisting of side sheets, top plate extrusions, side-sill extrusions and side-post extrusions.

The center sills, consisting of two railroad half-sill, mill-rolled steel sections (51.2 lb/ft), are automatically welded. These sills are cut, punched, matched and prepared for welding draft lugs, as well as ribs and key slot reinforcements, to the ends and inner face of each half sill. The half sills are next jig assembled and tack welded to form the boxed sill (102.4 lb/ft).

This boxed sill is moved to a submerged-arc automatic welding machine to make a continuous $^{9}/_{16}$-in. butt weld the full length of the sill. The inside is first sealed with $^{3}/_{16}$-in. diam wire using 600 a-c amp, 35 v, at 30 ipm. Next, the outside is made at a speed of 55 ipm, triple arcs, twin $^{1}/_{8}$-in. diam wires, at 1250 d-c amp with a trailing $^{3}/_{16}$-in. diam wire at 750 a-c amp. This affords overlapping penetration with acceptable reinforcement and good surface appearance.

The welded sill is now placed into the underframe assembly jig where the prefabricated bolsters, strikers, end sills and diagonal bracing are attached along with center fillers, riveted aluminum extrusions (Fig. 1 (*f*)) and bolster plates. The aluminum is insulated from the steel by a zinc-chromate primer and a butyl rubber calking compound. The underframe assembly is now ready for the welding roll-over position where all external and internal welds are made in the downhand position.

Figure 5 illustrates how a standard-type traveling manipulator is used with the subassembly jigs lined up adjacent to the manipulator track. The jigs are loaded, automatically welded and unloaded in a continuous cycle 24 hr a day. This Fig. 5 also shows butt welding of slope sheet using $^{3}/_{32}$-in. diam wire, 390 amp, at 24 ipm. In addition, two stationary manipulators are used to weld the extruded floor stiffeners to the floor sheets using $^{1}/_{16}$-in. diam wire for $^{3}/_{16}$-in. continuous fillet weld.

The end-slope sheet butt-welding machine is

Fig. 8—Body bolster, upper and lower floor sheets and cross-ridge assembly

Fig. 10—Automatic welding of side stakes, employing automatic welding heads on each side

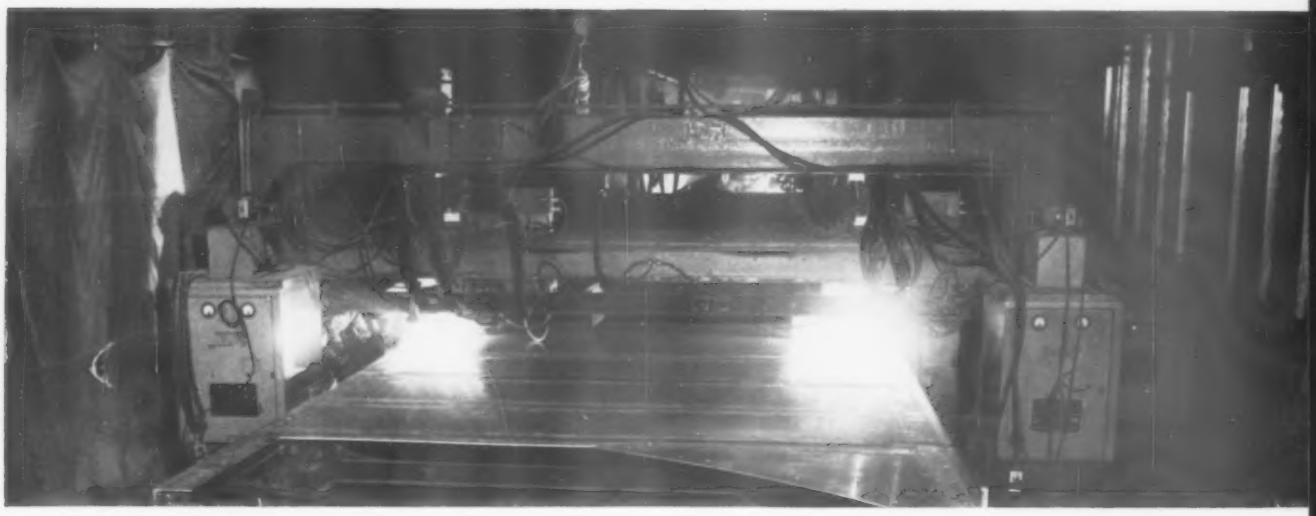


Fig. 9—Automatic welding of side sheets to top and bottom extrusions

shown in Fig. 6. The body bolster composed of an extruded section split on center, bevel 45 deg., forms two tee sections. These tees are welded to a $^{1}/_{2}$-in-thick web plate, using $^{3}/_{32}$-in. diam wire, 30 v, 425 amp and two passes at 28 ipm (see Fig. 1-*e*). Floor-sheet gusset assemblies—two right- and left-hand gusset plates—are welded to extruded tee sections.

Figure 7 illustrates manual welding of floor sheet and gusset assembly and body bolster and lower floor sheet, using $^{1}/_{16}$-in. diam wire.

Body bolster and upper and lower floor sheets are shown in Fig. 8. (This assembly forms each end of car, completing the principal car-end assembly. Allowances for shrinkage were predetermined in the fixtures prior to welding.) The cross-ridge and center partitions are assembled in a similar manner, forming the center assembly, one for twin, two for triple and three for quadruple hoppers.

The sides, Fig. 9, are prefabricated from the top and bottom side-sill extrusions, side-stake extrusions, side sheet and roping bars.

The side sheet plus the extruded shapes (top and bottom) are placed into a fixture and tacked to form the top and bottom seams (see Fig. 1-*b*, *c*). This is the first position in the side assembly line employing two semiautomatic consumable-electrode guns. The jigs release the sides and pass over rollers to the first seam-welding gantry.

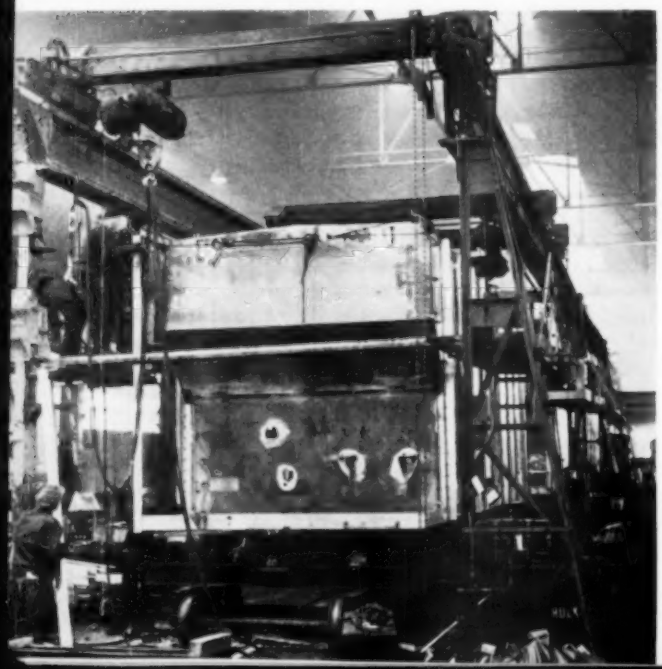
Tacking and Welding

The automatic welding heads weld the $^{5}/_{16}$-in. top and bottom butt seams simultaneously in a single pass, using air-pressure rollers bearing both members against a stainless-steel backing bar, employing $^{3}/_{32}$-in. diam welding wire at 370 amp, 29 v, at 18 ipm. This assures 100% penetration from one side and a good reinforcement on stainless-steel backing bar. After completion of these welds, the side is again rolled to the stake gantry for installation of side-stake extrusions (see Fig. 1-*d*).

The indexing holes (Fig. 10) in the gantry track locate the crosshead over each stake where air cyl-

Fig. 11—Subassembly being moved by crane and placed on shop trucks in the first position

Fig. 12—End view of assembly line showing sides with erection bolts



inders lock and press stakes to the side. Two automatic welding heads deposit a $^{3}/_{16}$-in. fillet on each side of extruded shape employing $^{1}/_{16}$-in. diam wire at 320 amp, 26 v, at 55 ipm. The side is then passed to the last position where miscellaneous small parts are tacked and manually welded. Here the side is reinspected and, if necessary, repairs are made prior to storage for assembly on line.

Adjacent to the assembly track (Fig. 11), the prefabricated body-bolster center partition and hopper outlets are jig assembled to the underframe. This unit is removed by crane and placed on shop trucks in the first track position. The sides are then applied. Side sheets are stored at end of production line for installation on cars.

The car (Fig. 12) is then moved progressively along the track past several welding stations where all flat welding to the underside is completed and roof carlines, Fig. 1 (*a*), are applied.

The cars are lifted from the trucks (Fig. 13) and placed between head and tail rotating jig stocks, rotating 90 deg. in both directions for the completion

Fig. 13—Bottom view of car in rotating jig for completion of all welds in the flat position

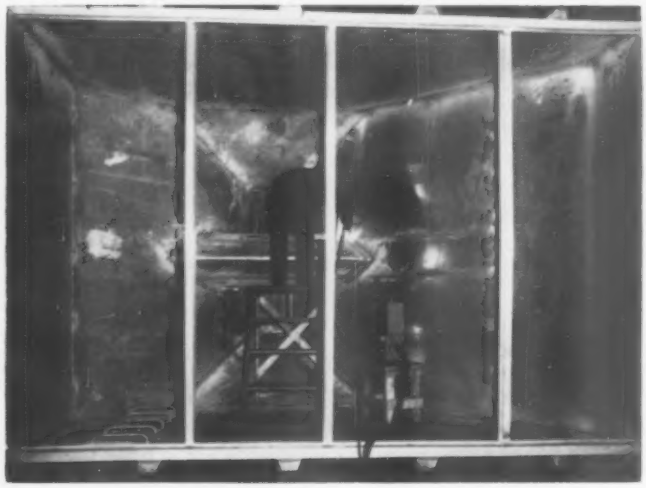


Fig. 14—Welder inside of car completing weld of cover plate in flat position

Fig. 15—Welding operator tacking roof sheets to carlines, employing 1-lb hand gun

of all welding that would otherwise be out-of-position work. Here, again, a complete inspection is made for quality, and the necessary repairs are made.

Figure 14 shows one of 12 welding machines on the quadruple, six on each side. All welding is in flat position.

From the rotating fixtures, the car body is returned to the track where roof sheets are placed into position and tack welded on the underside to the roof carlines Fig. 1 (*a*), 2 in. on 12-in. centers, employing manual equipment (air-cooled, 1-lb guns), $^{3}/_{64}$-in. diam wire and $^{3}/_{16}$-in. fillet welds.

The car is moved (Fig. 15) to the first high-gantry roof-welding position (note tacking overhead). Here two automatic heads deposit a $^{3}/_{16}$-in. fillet weld, welding the roof sheets to the top-side extrusion.

Figure 16 (over-all shot) shows the car traveling on to the next high gantry where the roof sheets are butt welded to the carlines, employing $^{1}/_{16}$-in. diam aluminum wire, and a general view of the welded center sill.

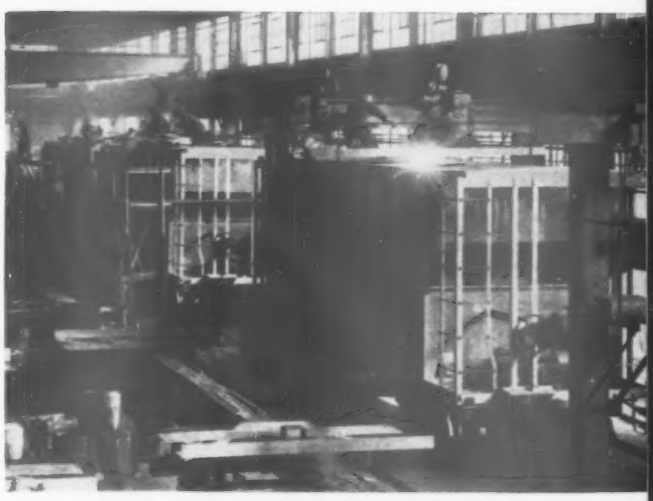


Fig. 16—Automatic welding of roof sheets to the carlines, employing high-gantry welding machines, subassembly center sills and running boards

Cast-aluminum hatch frames, alloy 356 permanent mold, shown in Fig. 17, are positioned, tacked and welded over the roof hatch openings, using $^{3}/_{64}$-in. diam wire for $^{3}/_{16}$-in. fillet, employing pull-type guns. The prefabricated assembled hatch covers are attached to car at this position.

The preassembled running board is placed into position and welded to the roof, completing the car.

The car is then water tested and visually inspected prior to stenciling.

Figure 18 shows the completed quadruple aluminum covered-hopper car, "the world's largest."

Conclusion

How the new cars will compare with standard cars in gross weight, payload and tare weight have been shown in Table 1.

Results of the cars' use will, in any event, be watched with interest, since the order represents the first large-scale application of aluminum to railroad freight cars in North America. Since this initial order, Southern placed an order for seven hundred and fifty 100-ton gondola cars, and another railroad ordered 200 open-top, 100-ton hopper cars to be built with aluminum sheet, plate and extrusions. These two orders have been placed with other car builders.

Some roads have built a few aluminum cars, principally for demonstration or experimental purposes. Some U. S. railroads have applied aluminum components, such as doors, roofs and liners, to conventional box refrigerator cars. But no North American railroad, up to now, has specified the lightweight metal so extensively, in so many cars, as the Southern Railway System.

Fig. 17—Cast-aluminum hatch frames tacked and welded over the roof-hatch openings

Fig. 18—Completed quadruple aluminum hopper car—the world's largest covered-hopper car

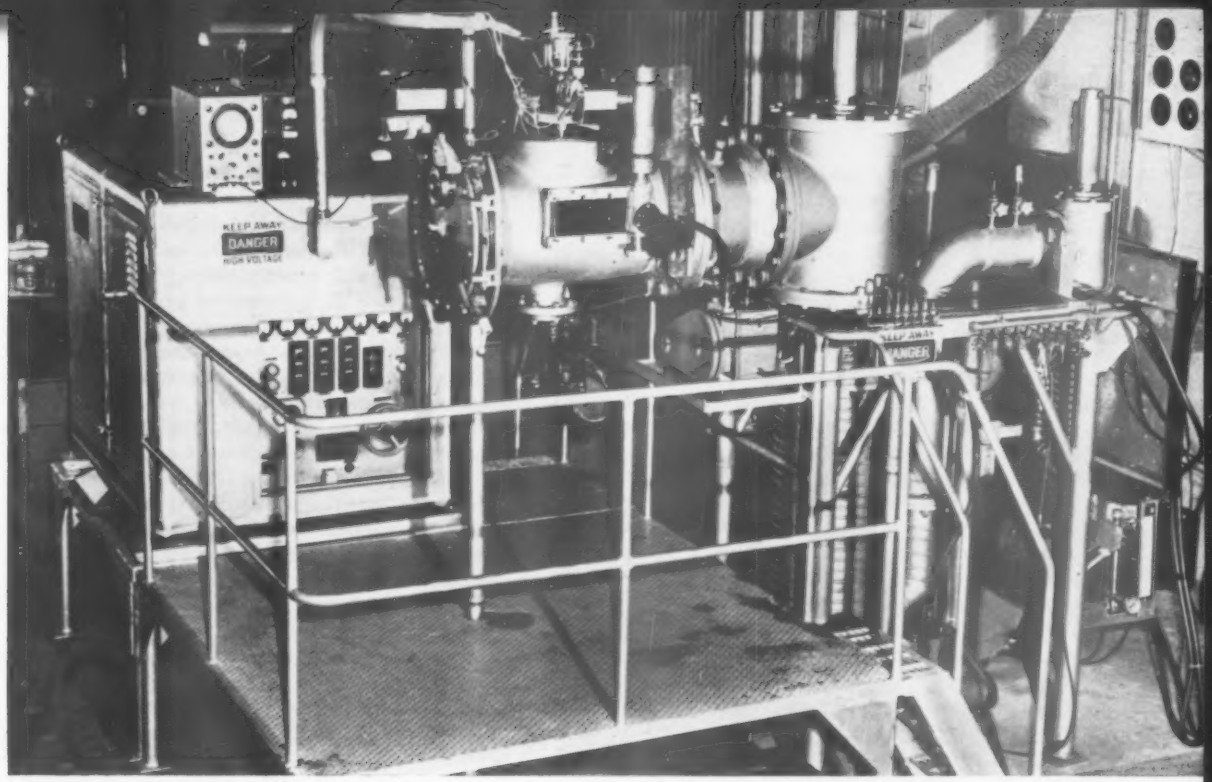


Fig. 1—Laboratory model of electron-beam welding machine

Equipment for electron-beam welding is rapidly changing in character toward meeting the requirements of reliability and ease of adjustment imposed by service requirements. This has led to the development of

A New **Electron-Beam** Welding Unit

BY W. J. GREENE, R. R. BANKS AND R. M. NIEDZIELSKI

High-power electron beams in vacuum have recently been adapted for several metallurgical processing applications. Ingot casting and refining of high-temperature or reactive metals is now being performed on a commercial scale.

Zone refining of semiconductor materials and welding of metals belonging to the high-temperature or the reactive-metal group are additional applications performed on an experimental basis. Equipment for electron-beam welding is rapidly changing in character toward meeting the requirements of reliability and ease of adjustment imposed by this type of service.

Types of Apparatus

At present, both high-voltage (50 to 100 kv) and low-voltage (10 to 30 kv) types of welding equipment are available. The low-voltage apparatus is less critical in adjustment and more easily operated, although the minimum focused spot size is several times greater in diameter than that obtained with high-voltage apparatus. In low-voltage equipment, those X-rays which are produced are soft enough to be absorbed by the walls of the evacuated chamber. Direct viewing ports may be provided to observe the welding position during operation. High-voltage equipment requires lead shielding of appropriate thickness and indirect optical viewing systems.

Internal gaseous breakdown in the electron gun due to entrapped gas or metallic vapor liberated from the workpiece is a serious problem which plagues the electron-beam welding process. This problem is more difficult to circumvent at higher electrode voltages.

For general-purpose welding, low-voltage equipment is preferable. However, in special applications

W. J. GREENE, R. R. BANKS and R. M. NIEDZIELSKI are associated with the Air Reduction Co., Inc., Murray Hill, N. J.

Paper presented at the AWS 41st Annual Meeting held in Los Angeles, Calif., April 25–29, 1960.

where exceptionally high depth-to-width ratio is needed in the penetration pattern, high-voltage apparatus may be necessary.

General

Electron-beam welding apparatus consists of an electron gun with associated optics for shaping and focusing the beam; a welding chamber equipped with viewing ports, vacuum-sealed door for easy access to the interior, and suitable mechanical devices to permit relative motion between the workpiece and the focused spot of the electron beam; an evacuating system to pump down and maintain high vacuum in the welding chamber and electron-gun structure; and an electrical system consisting of power supplies, regulating devices and control equipment for the electron gun, mechanical pumps and motorized drives.

The $7^1/_2$-kw laboratory-model electron-beam welding machine shown in Fig. 1 was constructed to obtain process data and to refine and improve electron optics and associated control equipment. The power supply employed in this unit is rated $^1/_2$ amp. at 15,000 v and was originally intended for use in an Army Early Warning Radar system.

From information obtained with the laboratory model, a commercial unit was designed and constructed. This unit is shown in Fig. 2. The characteristics are substantially identical with those of the laboratory model, differing mainly in the use of a larger welding chamber to accommodate larger workpieces, and the addition of a power supply specifically designed for the application, providing greater convenience in control and operation.

Electron Optics

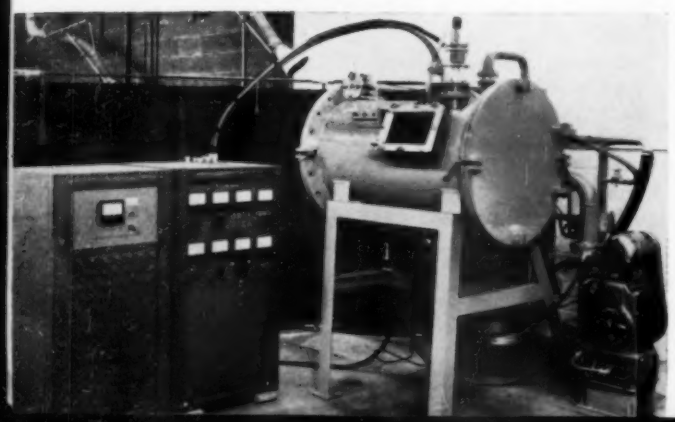
The earliest type of electron-optics system used for welding consisted of a simple aperture lens. In this type of gun, a heated tungsten filament is positioned a few millimeters behind a circular hole in sheet metal maintained at the same potential as the filament. A potential between the workpiece and the aperture accelerates the electrons emitted from the filament and converges the beam to a focused spot. This is an immersion-type electrostatic focusing system.

The simple aperture lens system places high-voltage elements within a few centimeters of the workpiece. Gases and metallic vapor released in welding operation cause flashover or gaseous discharge, particularly at high-input power (1 kw or more) and during the welding of metals or alloys which contain entrapped gases or which have a high-vapor pressure at the melting point of the workpiece. The electron gun also obscures vision so that it is difficult to observe the welding process. Focusing must be performed by mechanically raising or lowering the gun structure.

The next step in the development of electron optics for welding involved the use of an electromagnetic focusing system to refocus the beam from an aperture lens so that the gun structure and high voltages could be removed from the immediate vicinity of the weld zone. Although this system permitted observation of the welding and lowered the sensitivity to gaseous breakdown, the latter problem was still very serious at high power. The ability to focus electrically without mechanical motion was a decided advantage.

The problem of gaseous breakdown was solved in the next step by using a double magnetic-lens system. A small orifice at the crossover point between the electromagnetic focusing coils allowed passage of the electron beam but served as a diffusion barrier to inhibit the flow of gases or metallic vapor from the welding chamber into the electron gun proper. The beam emerging from the orifice then passes through field-free space to the workpiece. The arrangement of elements in the electron optical system is shown in Fig. 3. Gas flow through the

Fig. 2—Commercial model of electron-beam welding machine



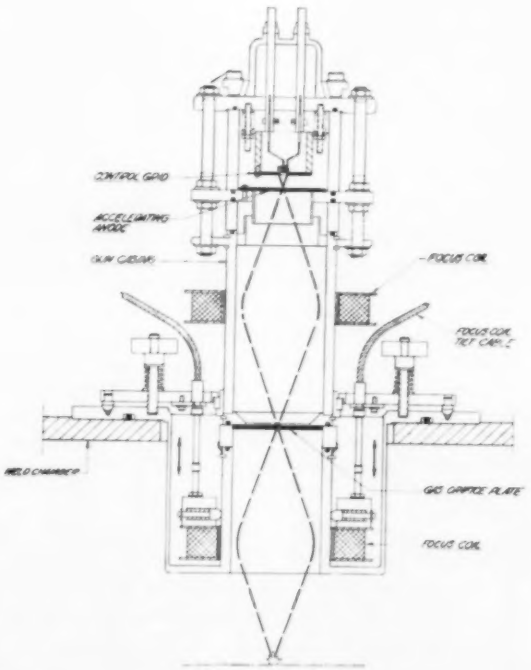


Fig. 3—Electron optical system

orifice plate is limited to diffusion since the diameter of the orifice is small compared to the mean free path of gas molecules within the welding chamber.

A serious problem was introduced by this construction. If perfect focus is not maintained by the upper focus coil, the crossover point will not occur at the orifice. At high-power and improper focus, the beam will pierce a larger hole in the orifice plate. Current in the beam is increased by reducing the d-c bias on the control grid. To maintain crossover at the orifice at higher currents, the current in the focus coils must be increased slightly. Space-charge effects introduce this dependency. The difficulty in maintaining focus coil adjustment by manual means made it imperative to develop automatic focusing means. The block diagram for a transistorized control using the current flow to the orifice plate as a sensing signal is shown in Fig. 4. A portion of the output is also introduced into the lower focus coil to compensate for the space-charge effects in that portion of the beam. Preset focus conditions

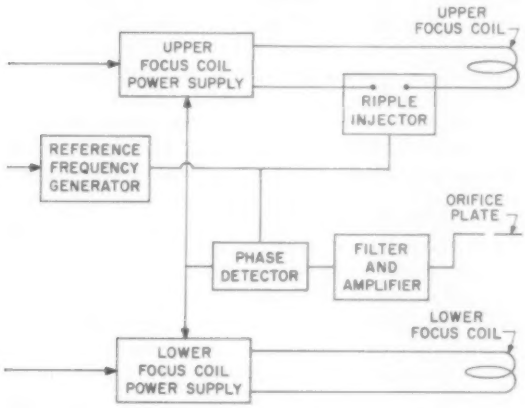


Fig. 4—Block diagram of automatic focus control

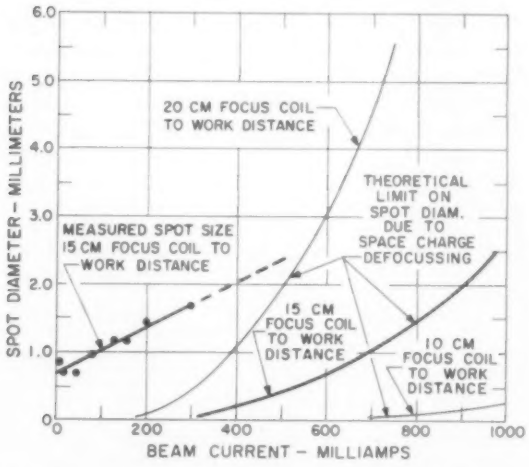


Fig. 5—Comparison of actual spot size with theoretical limitation due to space-charge effects

in the lower coil can be maintained with changes in beam current.

Current picked up by the orifice plate passes through a sharp minimum as the current in the upper electromagnetic lens is increased through the value which places the focus at the orifice. When a small alternating current is introduced into the upper lens, a ripple of the same frequency will appear in the iris current. The phase of this ripple will reverse 180 deg on passing through the focus. At focus, the fundamental frequency of the ripple will reduce to zero, leaving a small double-frequency component. By comparing the phase of the ripple in the orifice plate current with the phase of the alternating current introduced into the focus coil, a direction signal is obtained. The phase-sensitive detector performs this function. Sufficient gain is introduced into the circuit to maintain precise focus at the orifice. Since the circuit is operated in closed loop, any shift in focus will develop a signal at the output of the phase detector, which raises or lowers current to the magnetic lens to re-establish focus. Output transistors are also employed to filter out unwanted power-supply ripple in the focus-coil circuits. Focus is also maintained with normal variation in supply voltages.

The most serious problem in the design of electron optics for 15,000-v operation is the defocusing effect of space charge in the electron beam. In regions where electron trajectories converge to a focus, the mutual repulsion between electrons sets a lower limit on the diameter of the beam at the smallest cross section. The theoretical limit on focused spot size may be reduced by increasing the radial inward velocity of the electrons as they converge to a focus. At a given accelerating voltage, this may be effected by spreading the beam to a large cross section within the electromagnetic lens and converging to a focus at a sharp angle. Unfortunately, spherical and chromatic aberations increase with greater beam cross section within the magnetic lens. A beam diameter of 5 cm in the lens was selected as the best compromise. Excellent focus spot size is achieved up to full rating at a focus coil to work distance of 15 cm. At a distance of 20 cm. the reduction in angle of convergence will produce some deterioration in focus above two-thirds of rated power.

In Fig. 5 the theoretical limit on spot size due to space charge defocusing is plotted as ordinate with beam current as abscissa for 10, 15 and 20 cm, spacing from the plane of the lower focus coil to the workpiece. The measured spot size is also plotted for a 15-cm spacing. Readings above 330 ma could not be obtained due to limitations introduced by the measuring equipment. Measurements were obtained by rotating a 0.020 in. diam tungsten wire at 1000 rpm through the focused beam. Beam current intercepted by the wire was measured and displayed on a cathode-ray oscilloscope synchronized with the speed of rotation. A typical oscillographic display

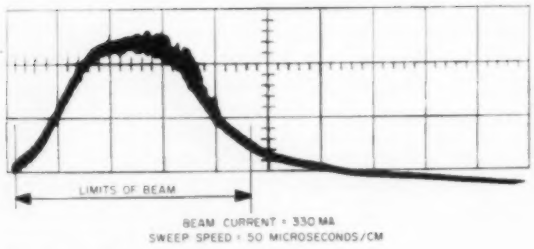


Fig. 6—Oscillographic trace used as a basis for spot-size calculations

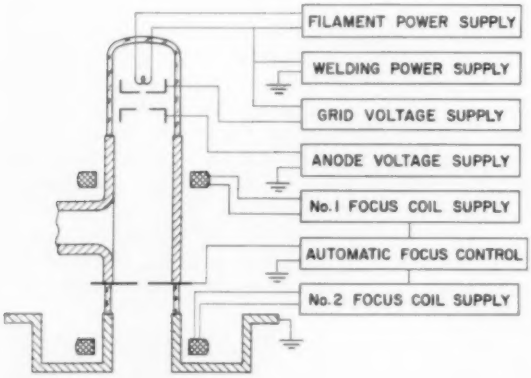


Fig. 7—Power supplies

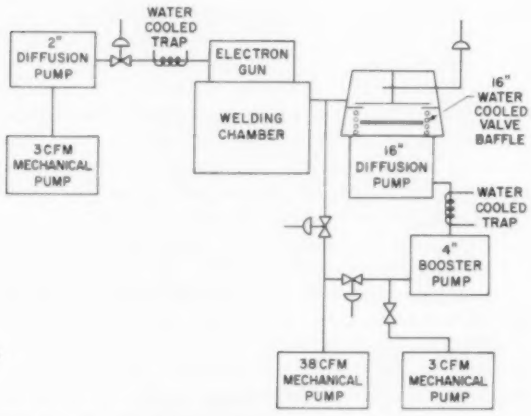


Fig. 8—Diagram of evacuating system with pumps and valving

is shown in Fig. 6. Beam diameter was determined by calculation from photographs of the displays. The diameter of the focused spot varies from less than 1 mm in the low-power range to less than $2^1/_2$ mm at maximum rating.

As the construction of the electron gun was a new undertaking at the Laboratories, a modular design was used to permit adjustments and modifications to be made without rebuilding the entire gun. The structure comprises alternate rings of heavy-wall Pyrex pipe and disks of brass or aluminum which support the gun elements. Seals are made by

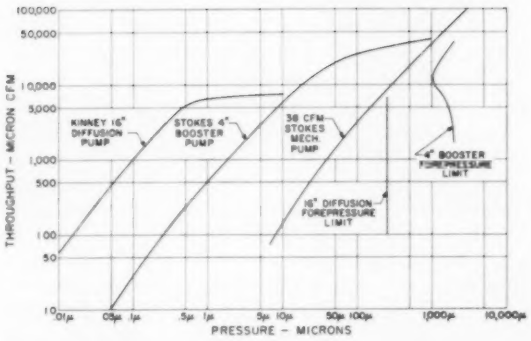


Fig. 9—Pump throughput characteristics

means of O-rings in the metal disks. The filament, grid and anode are supported so that the spacing can be readily adjusted if necessary. The focus coil is supported so that it may be tilted to align the beam on the work. This movement is about $^3/_8$ in. from the center in any direction. The entire gun assembly is mounted on a standard 8-in. ASA 150-lb flange.

Power Supplies

A block diagram of the power supplies needed for operation of the electron gun is shown in Fig. 7. Ratings of these supplies are as shown in Table 1.

Vacuum System

Electron-beam welding must be performed in a chamber evacuated to a pressure of about 0.1 micron (1.3×10^{-7} atm). To attain pressures in this range, diffusion pumps are required. The pumps must have sufficient capacity not only to evacuate the chamber to the operating pressure within a reasonable time, but also to remove gas evolved when the metal being welded is melted in vacuum.

A rough estimate of the quantity of gas that could be evolved by gassy metal when welding at maximum power showed that a capacity of 10,000 cu ft of gas at 0.1 micron, or 37 cu cm at atmospheric pressure, was needed. The main diffusion pump selected is a 16-in. ring jet-type pump which has a nominal capacity of 11,500 cfm at 0.1 micron.

Table 1—Rating of Power Supplies

Filament supply.....	0–12 v, 30-amp ac, continuously variable; current and voltage metered
Welding-power supply	15 kv, 500-ma dc, derived from full-wave rectified 3-phase 220/440 v 60 cycle input; output current and voltage metered
Grid supply.....	0–2 kv, 1-ma dc, continuously variable; voltage metered
Anode supply.....	0–10 kv, 0.5-ma dc, continuously variable; voltage metered
Focus-coil supplies...	40 v, 3-amp dc, continuously variable; current metered

The poppet valve and baffle used with this pump caused some reduction in pumping rate. In view of a potential gas load in excess of the diffusion-pump capacity, it was decided to back the diffusion pump with an oil booster pump. A booster pump has its maximum capacity at 10 microns, where neither the diffusion pump nor the mechanical pump is effective. Thus, it rapidly "clears" gas bursts that exceed the capacity of the diffusion pump and, in addition, maintains the forepressure of the diffusion pump at a lower pressure than practicable with mechanical pumps. In cases where pump-down time is not appreciable because of the small size of the welding chamber, the cost of the booster is offset by the possibility of using a smaller mechanical pump.

The pumping system used with the laboratory welding machine is as follows:

16-in. ring jet diffusion pump, 11,500 cfm at 0.1 micron

6-in. ring jet booster pump, 1,150 cfm at 10 microns

110-cfm type KDH 8-8-10 mechanical pump

The welding chamber of the original laboratory model was designed to be capable of handling small weld specimens. A standard 16-in. welding tee was modified to form the chamber.

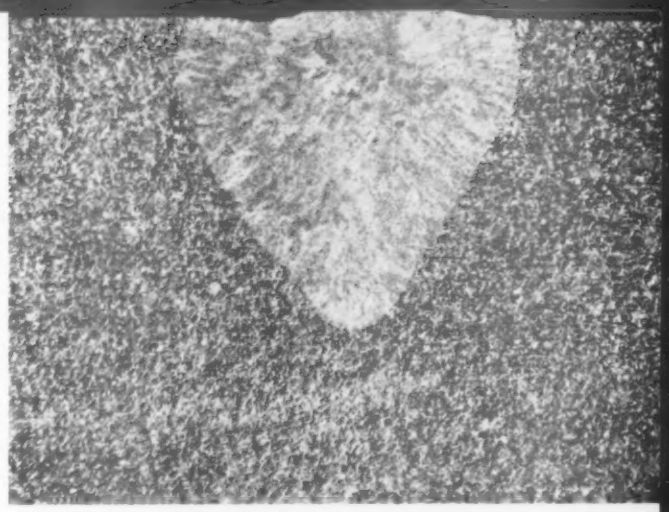
The chamber of the prototype commercial model is 2 ft in diam and 44 in. long to accept larger specimens and small production samples. Commercial availability of a shorter diffusion pump made possible the more compact design of this unit.

A diagram of the evacuating system with pumps and valves in schematic form is shown in Fig. 8. It should be noted that a separate diffusion pump and mechanical pump are provided for the electron gun. As the diffusion and booster pumps must be kept under vacuum while in operation, it is necessary to provide valves to isolate these pumps while the welding chamber is being loaded and unloaded. The system used also permits the large mechanical pump to be used alternately for "roughing" the chamber to a pressure where the oil-vapor pumps will operate, and for backing these pumps during normal operation. The 3-cfm pump is used to maintain the vacuum in the oil-vapor pumps while the system is being "roughed."

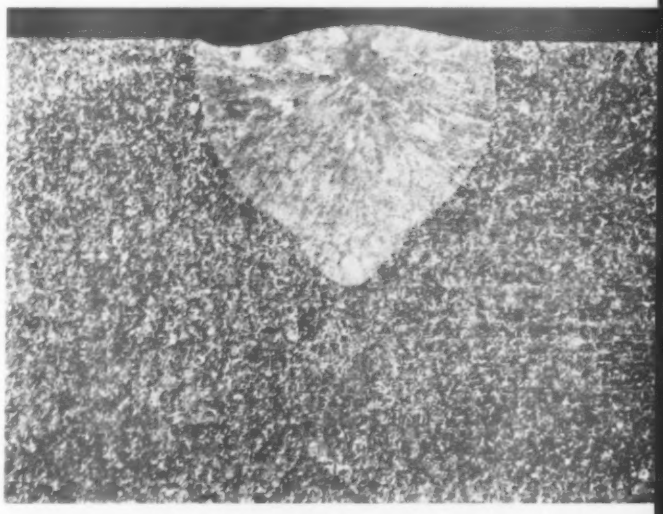
Figure 9 is a graph of the pumping rate in micron cubic feet per minute at various inlet pressures for each of the pumps. The maximum limit of the forepressure for the diffusion and booster pumps is indicated on the graph.

Welding Characteristics

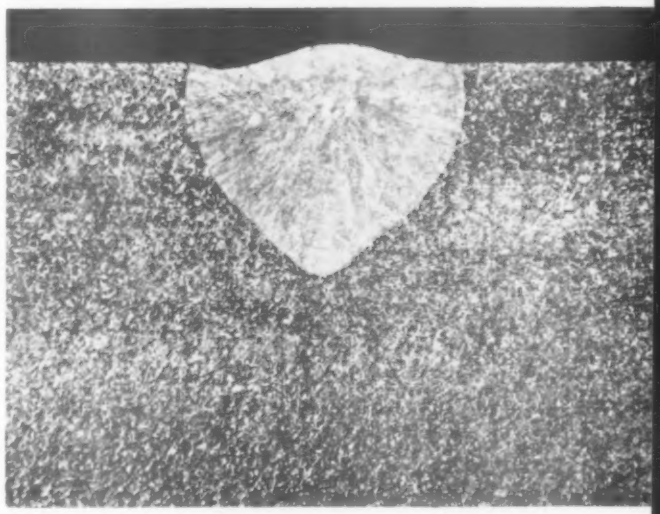
The energy input in electron-beam welding is converted to heat at the weld zone, with efficiencies above 90%. In conventional arc welding, the voltage drop at the welding electrode and in the arc column is largely lost due to radiation and conduction, giving efficiencies of approximately 50%. In addition, the electron beam can be focused to a



Specimen No. 1, 4 ipm



Specimen No. 2, 8 ipm



Specimen 3, 12 ipm

Fig. 10—Effect of travel speed on penetration pattern. Type 304 stainless steel 1/4 in. thick; constant current 70 ma, 15 kv

region of the order of 1 mm in diam, thus concentrating the heat at the exact spot where welding is taking place. For these reasons, the input power required to produce a given weld in electron-beam welding is considerably less than that required for conventional arc welding.

In Figs. 10 and 11 the effects of travel speed and beam current on the penetration pattern and bead contour are shown for the electron beam focused to the smallest diameter.

The complete absence of contaminants in the vacuum environment required for electron-beam welding makes it ideal for joining metals and alloys that are strongly reactive. Molybdenum, tungsten and beryllium are typical of such metals. Absolute soundness also can be more easily achieved in a vacuum since adsorbed and dissolved gases are removed from the molten metal during welding. It is for these two reasons that alloys intended for nuclear applications frequently are welded with this method.

The electron-beam process also allows greater control of welding variables, such as current level, force and diameter of the source of heat, than is possible with arc-welding methods. Materials in foil thicknesses are more easily joined. The higher depth-to-width ratio achieved with electron-beam welding permits relatively heavy sections to be welded with a minimum of distortion.

Many metals and their alloys can be welded with the electron beam; included in this list are aluminum, stainless steel, molybdenum and zirconium. Usual types of joints made with fusion arc methods have also been made with the electron-beam method using foil, sheet and plate thicknesses ranging from 0.005 to 0.250 in.

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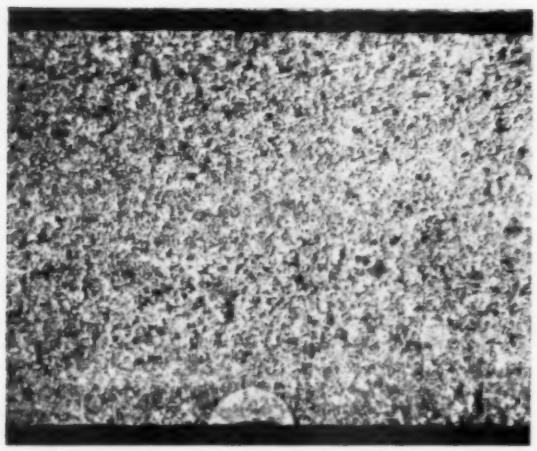
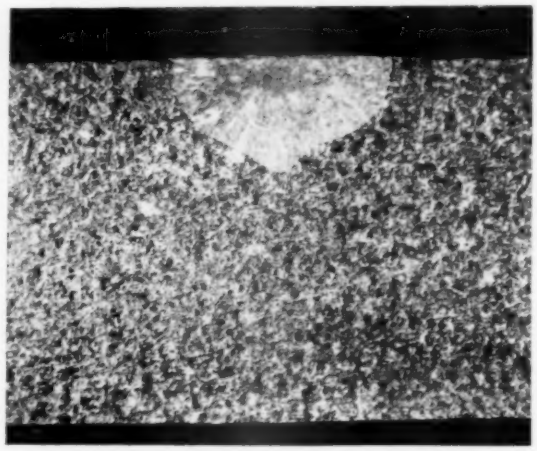
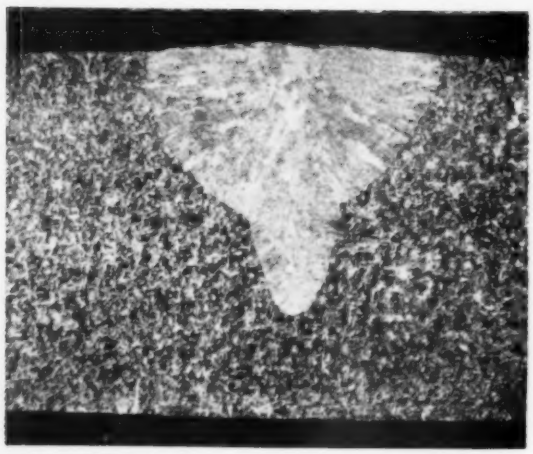


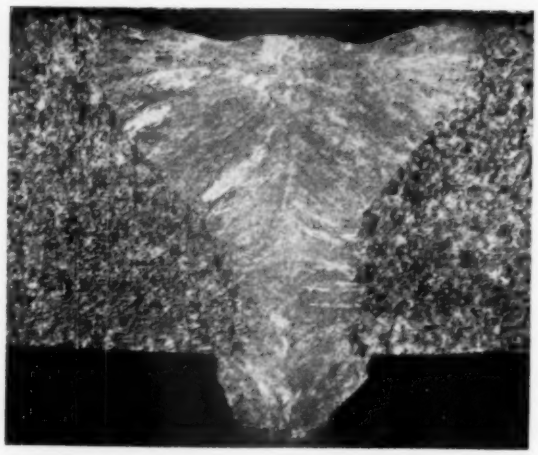
Specimen No. 1, 20 ma



Specimen No. 2, 50 ma



Specimen No. 3, 100 ma



Specimen No. 4, 150 ma

Fig. 11—Effect of beam current on penetration pattern. Type 304 stainless steel $^1/_4$ in. thick; constant speed 8 ipm, 15 kv

Mechanical properties are found to be related to joint misalignment during a laboratory

Evaluation of Misaligned Butt-Welded A-286 and Cr-Mo-V Sheet Material

BY D. E. HACKER AND S. WEISS

ABSTRACT. Mechanical properties of welded joints utilized by design engineers are usually based on data obtained from laboratory specimens joined under ideal conditions. These specimens are joined with little, or no mismatch of the abutting sheet edges. Current manufacturing and design practices in the aircraft gas-turbine industry specify a limit of approximately 5–10% mismatch based on this ideal-type design data.

Advanced sheet-metal designs for contemplated future applications are becoming more complex, leading to fixturing problems during fabrication and, thus, a greater propensity for increased mismatch.

This program was undertaken to determine the relationship which exists between the degree of mismatch and the resultant mechanical properties.

Introduction

Inert-gas-shielded tungsten-arc welding is used extensively in fabricating sheet components for the jet-engine industry. Design criteria for mechanical properties of sheet welded butt joints are generally obtained and based on data accumulated from laboratory-welded specimens with little or no mismatch.

It is anticipated that during the manufacture of large diameter and complex jet-engine sheet components on advanced designs, varying degrees of mismatch may occur. This investigation was undertaken to determine the relationship existing between the degree of mismatch and weld-joint mechanical properties. Two representative materials in jet-engine fabrication were used for the evaluation: (1) a low-alloy Cr-Mo-V steel, and (2) A-286 high-temperature age-hardenable alloy. Testing was restricted to mismatched sheet specimens of 0, 50 and 100%. Exaggerated conditions of mismatch were used in this study to detect readily the significant effects that may result in mechanical properties. The number of specimens for each condition could, therefore, be limited and further testing performed if warranted from the results obtained. The specimens were subjected to short-time tensile test at room and elevated temperatures, short-time stress-rupture and fatigue tests.

The evaluation was based on composite specimens consisting of reinforced welds, heat-affected zones and base material.

Fabrication of jet-engine component requires close control of mismatch conditions

Test Procedure

Materials

The sheet materials selected for this program were

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Paper presented at AWS 41st Annual Meeting held in Los Angeles, Calif., Apr. 25–29, 1960.

Table 1—Chemical Composition, %

Material	C	Mn	Si	Cr	Ni	Mo	Ti	V	Al	Fe	Cb
A-286	0.06	1.26	0.64	14.9	25.2	1.3	2.2	0.26	0.19	..	...
Modified Ni-Cr-Fe	0.04	0.54	0.28	14.5	71.9	...	2.7	...	0.68	..	0.98
Cr-Mo-V	0.20	0.55	0.90	1.1	...	1.0	..	0.14	...	..	...
Cr-Mo-V wire	0.18	0.53	0.90	1.1	...	1.0	..	0.14	...	..	...

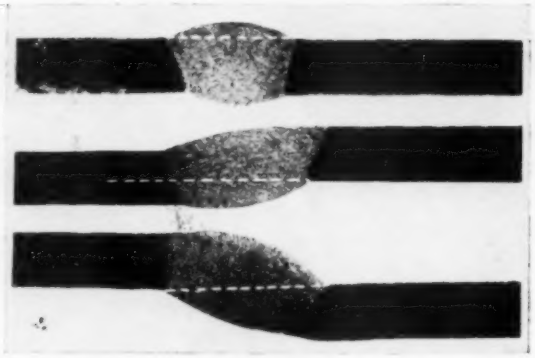

Fig. 1—Typical welded-specimen cross sections showing 0, 50, and 100% mismatched conditions

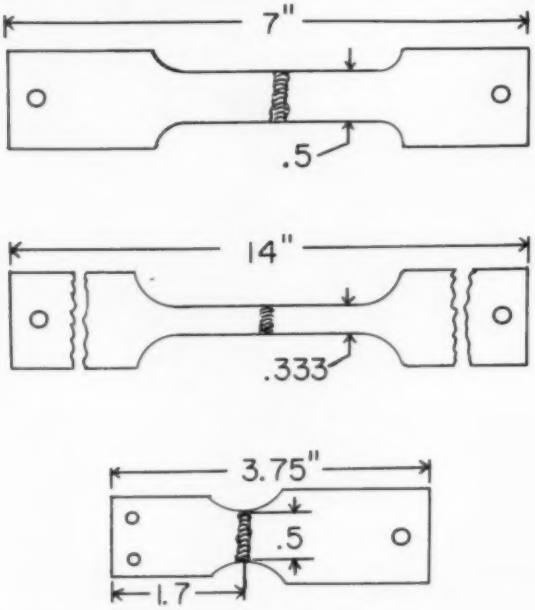

Fig. 2—Tensile, stress-rupture and fatigue specimens used for testing

A-286 and a low-alloy Cr-Mo-V steel. The sheet for all tests was limited to 0.062 in. nominal thickness. These materials were chosen as being representative of the austenitic precipitation hardening and the low-alloy martensitic class of steels used in aircraft gas-turbine applications.

The filler material used for joining A-286 was a modified nickel-chromium-iron alloy, a suitable filler from a mechanical property standpoint. The filler used for the Cr-Mo-V alloy closely matched the base-material analyses.

Table 2—Gas Tungsten-arc Weld Settings

Material	Mis-match, %	Current, amp	Speed, ipm	Torch gas, cfh	Argon backing gas, cfh
A-286	0	125	14	Argon 15	15
A-286	50	130	13	Argon 20	15
A-286	100	75	12	Helium 18	15
Cr-Mo-V	0	135	12	Argon 12	None
Cr-Mo-V	50	160	10	Argon 12	None
Cr-Mo-V	100	150	8	Argon 12	None

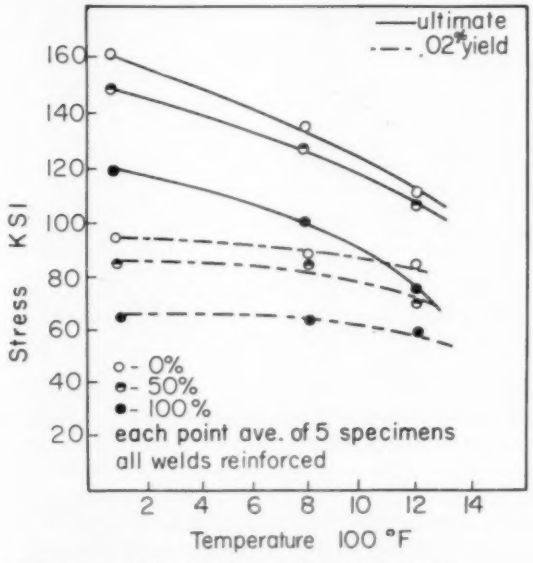

Fig. 3—Tensile strength of mismatched A-286 sheet

The chemical compositions of the base and filler materials used during the study are shown in Table 1.

The A-286 was received in the 1800° F solution-treated condition while the Cr-Mo-V alloy was received in the spheroidized-annealed condition.

Preparation of Test Specimens

The "as-received" materials were sheared into samples with the direction of rolling perpendicular to the direction of welding. The edges to be welded were mechanically cleaned with the use of an emery roll.

Welding was performed using the automatic

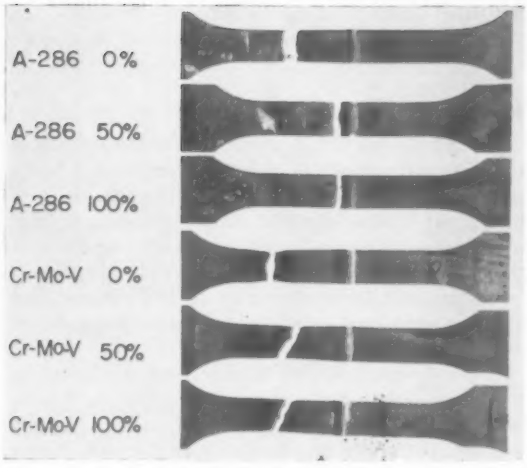

Fig. 4—Mismatched-tensile-specimen failure locations

gas tungsten-arc process with a side-arm wire feeder. Copper and argon-gas backing were used on all test samples. The welding conditions used for joining the samples are listed in Table 2. It was necessary to use helium torch gas on 100% mismatched A-286 samples in order to obtain satisfactorily penetrated joints for testing.

Samples were closely aligned, tacked and welded in a fixture which resulted in joints with zero percent mismatch. Fifty and 100% mismatched samples were obtained by using 0.031- and 0.062-in. thick shims respectively. Attempts were made to maintain weld-bead reinforcement and penetration as consistently as possible. Cross sectioning and macroexamination at the ends and center of the 12-in. long samples verified the degree of mismatch obtained as shown in Fig. 1.

Inspection of the weld joints was performed after welding and, again, after heat treatment. All welded joints were subjected to radiographic inspection. In addition, the A-286 and Cr-Mo-V samples were inspected by fluorescent penetrant and magnetic-particle methods respectively for possible surface defects. No significant defects were observed in the welds inspected. Minor porosity was found in a few areas in the Cr-Mo-V samples, but were avoided by discarding these portions of the samples.

The A-286 samples were solution heat treated at 1650° F for 2 hr and aged at 1300° F for 16 hr. The Cr-Mo-V samples were normalized at 1725° F for 30 min, rapidly air cooled, and tempered at 1200° F for 2 hr.

Stress rupture, fatigue and room and elevated temperature tensile specimens were machined from the welded samples as illustrated in Fig. 2. The weld-bead reinforcement and penetration were not machined away.

Testing

A-286 tensile specimens were tested at room, 800 and 1200° F in a standard testing machine at a strain rate of 0.005/in./in./min. The Cr-Mo-V tensile specimens were tested under similar conditions with the exception that the 1200° F tests were omitted.

The A-286 fatigue specimens were tested at room temperature in a mechanical constant-load flexure machine while the Cr-Mo-V specimens were tested in an electromagnetic drive apparatus. The nominal stresses applied to the weld joints of both materials were calculated from the basic equation:

$$S = \frac{MC}{I}$$

where

S = outer fiber stress, psi
M = moment, lb-in.
$C = \frac{t}{2}$ where t = thickness of specimen, in.
I = moment of inertia, in.^{4}

The A-286 stress-rupture specimens were tested in a single-station furnace at 1200° F. No stress-rupture testing was performed on the Cr-Mo-V alloy since the alloy is designed for service conditions at or lower than 900° F. Hence, no emphasis was placed on this phase of testing.

Results

Tensile Tests

A-286. The ultimate and 0.02% yield-strength data for the A-286 specimens is shown plotted over a range of temperatures in Fig. 3.

Base-metal tensile-test data were essentially the same as the welded specimens with 0% mismatch and, therefore, are not shown in Fig. 3. The room-temperature elongation measured in a 1-in. gage length was as follows:

(*a*) 0% mismatch, % 9
(*b*) 50% mismatch, % 6
(*c*) 100% mismatch, % 3.0

The 0% specimens fractured in base metal not in the vicinity of the welds. The 50 and 100% mismatched specimens failed at the weld interface, as shown in Fig. 4, with little or no straightening at the mismatch section (see bottom of Fig. 6).

Cr-Mo-V. Figure 5 shows the tensile data obtained from the Cr-Mo-V specimens at room temperature and 800° F.

All fractures occurred in the base metal approximately $^3/_4$ in. from the welds (see Fig. 4). Since fracture was consistently located in the base metal, a 2-in. gage length was used to include the plastic deformation at the fracture location. The elongation of base metal, zero, 50 and 100% mismatch specimens was 10 to 11.5%.

After testing, it was observed that the tensile and moment forces acting at the weld joint of the 50 and 100% specimens resulted in a straightening effect, as shown in Fig. 6.

A-286 and Cr-Mo-V Fatigue Tests

The fatigue-test results are presented in Figs. 7 and 8. The base-metal curve was obtained from previous design data with material chemistry close

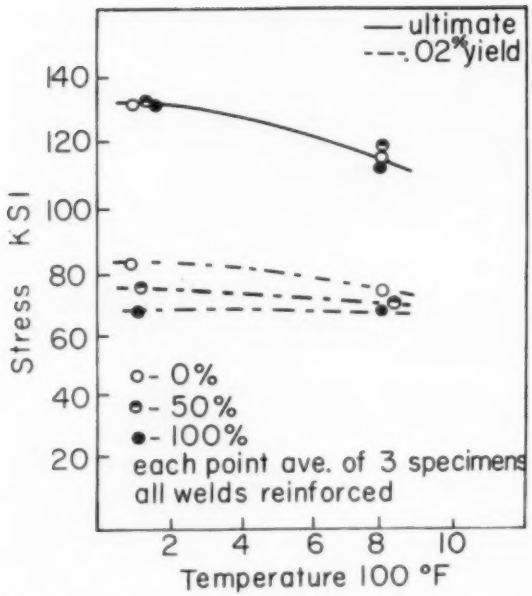

Fig. 5—Tensile strength of Cr-Mo-V mismatched sheet

to that of the welded specimens used in this investigation. All failures occurred intragranularly at the edges of the welds.

A-286 Stress-rupture Tests

The stress-rupture test results are shown in Fig. 9. Failures in the 0% specimens occurred in the base metal not in the weld vicinity. The 50 and 100% specimen failures occurred at the weld interface. Fractures were intergranular in nature. No straightening occurred at the mismatch weld sections.

Discussion of Results

The test results obtained clearly show a reduction in mechanical properties of weld joints having exaggerated mismatch conditions (see Figs. 3, 5, 7, 8 and 9). It is also apparent from the test data that an increase in the degree of mismatch results in a further lowering of the mechanical properties. The ultimate tensile strengths of the mismatched Cr-Mo-V weld joints were the only data not reduced (see Fig. 5).

Figure 4, which shows typical fracture locations in the base metal far removed from the weld joint and heat-affected zone indicates that ultimate base-metal strength was being tested for each degree of mismatch.

Tensile loading of mismatched specimens results in tensile stresses, as well as a moment over the entire specimen with the peak values at the weld joints. For a given load indicated on the tensile-testing machine the moment caused additional fiber stresses which were believed to be a major factor in lowering the final test results.

Since the mismatched Cr-Mo-V specimens exhibited relatively good ductility across the joint, the moment arm decreased with increasing load until complete straightening occurred, as shown in Fig. 6. Failure was then initiated in the base metal away from the reinforced weld.

This was not the case for the misaligned A-286 welded specimens. The weld joints exhibited low

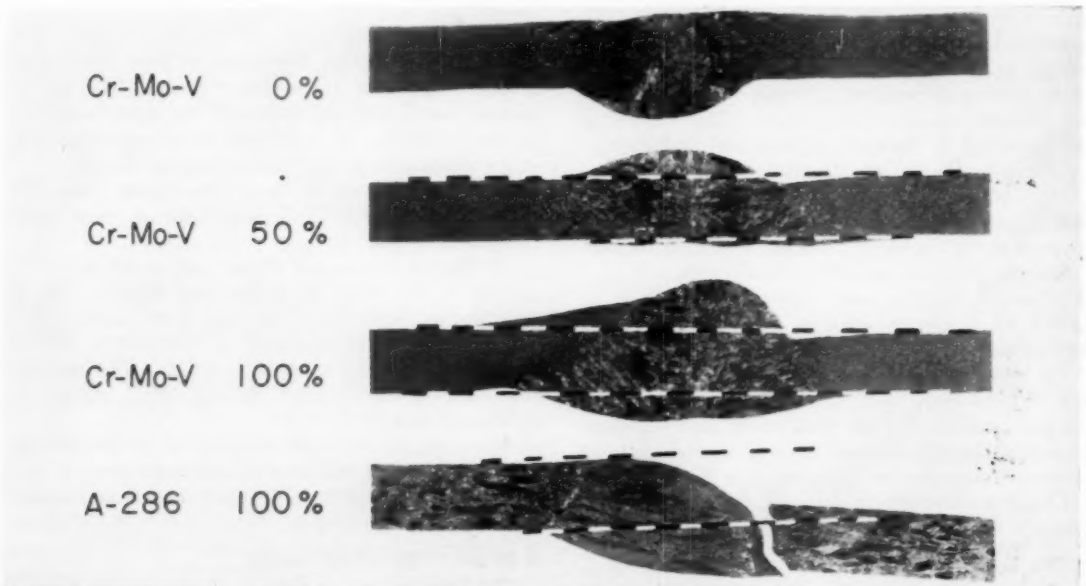

Fig. 6—Typical weld-joint cross sections after tensile fracture. Note A-286 mismatch remaining as compared to complete straightening on the Cr-Mo-V specimens

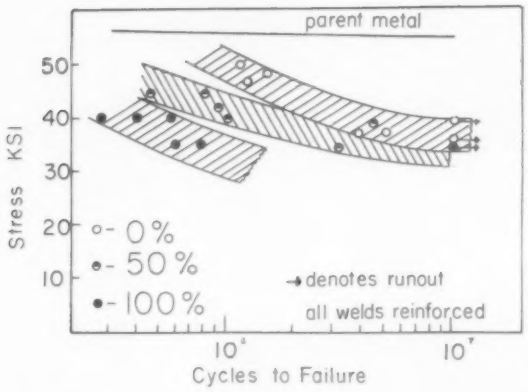

Fig. 7—Stress-endurance curves for A-286 butt-welded mismatched sheet

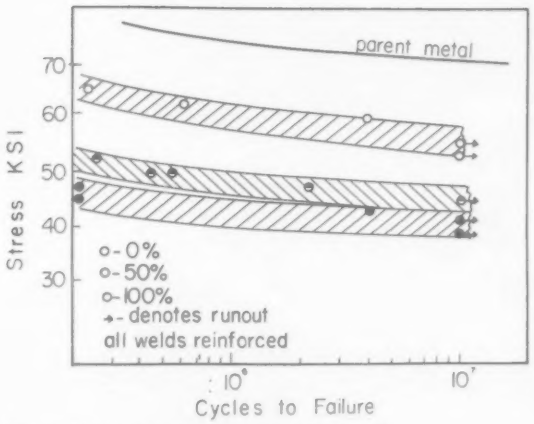

Fig. 8—Stress-endurance curves for Cr-Mo-V butt-welded mismatched sheet

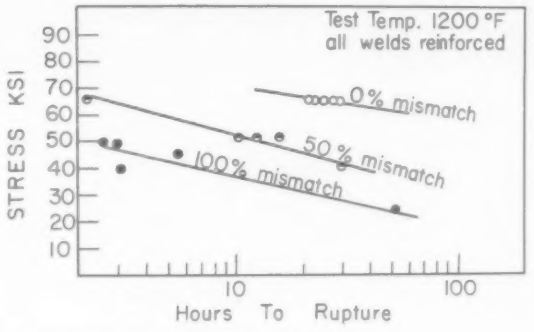

Fig. 9—Stress-rupture curves for A-286 butt-welded mismatched sheet

ductility and only slight straightening occurred during testing (see Fig. 6). Maximum fiber stresses prevailed in the vicinity of the weld joints during the testing, resulting in a substantial lowering of the recorded yield and ultimate-strength values. Tensile failures of the mismatched specimens were consistently located at the weld heat-affected zone interface, as shown in Fig. 4.

In summary, the static tensile-test results indicate that the major contributing factor in enhancing lowering of properties is the moment forces acting at the weld joints. Ductility at the weld joint is believed to be important in that it determines the degree of straightening which can occur during testing. It appears that the "notch effect" created by the weld reinforcement does not play a major role in reducing the tensile properties.

Observation of mismatched A-286 stress-rupture test specimens revealed that no straightening had occurred. It is believed that the same phenomena responsible for lowering the tensile properties caused the lowering of the stress-rupture properties.

Reduced fatigue properties were anticipated and obtained quantitatively as shown in Figs. 7 and 8. The predominant factor causing a lowering of fatigue strength was the "notch effect" at the edge of the weld reinforcement, the point from which all fractures initiated. This "notch effect" depends entirely on the shape of the reinforced weld as related to height, width and contour angle between the weld and sheet-material surface. In general, an increasing degree of mismatch causes an increased "notch effect" which correspondingly lowers the fatigue strength.

Conclusions

1. Tensile and stress rupture properties of severely mismatched A-286 welded joints in 0.062-in. thick sheet are substantially lowered.

2. Ultimate tensile properties of severely mismatched Cr-Mo-V welded joints in 0.062-in. thick sheet are not affected, whereas apparent yield properties are lowered.

3. Severe misalignment of 0.062-in. thick A-286 and Cr-Mo-V welded joints substantially reduces fatigue properties.

4. The lowering of tensile and rupture properties are believed to be enhanced by moment forces and increased fiber stresses acting in the mismatched area.

Recommendations

It has been shown that exaggerated weld-joint mismatch on a specific sheet thickness of two representative materials used in the jet-engine industry results in considerable reduction of mechanical properties. Additional work is required to determine the effects of lesser degrees of mismatched, welded A-286 and Cr-Mo-V sheet for various sheet thicknesses. Further work in this direction on other widely used materials would give a basis for establishing engineering mismatch limits in the manufacturing of sheet components.

Acknowledgment

The authors wish to acknowledge the assistance given by the following laboratory and design personnel in conducting this investigation: D. P. Kerwick, E. Swim, T. Welch, F. Schantz, E. Wheeler, M. Reiff and G. Gray.

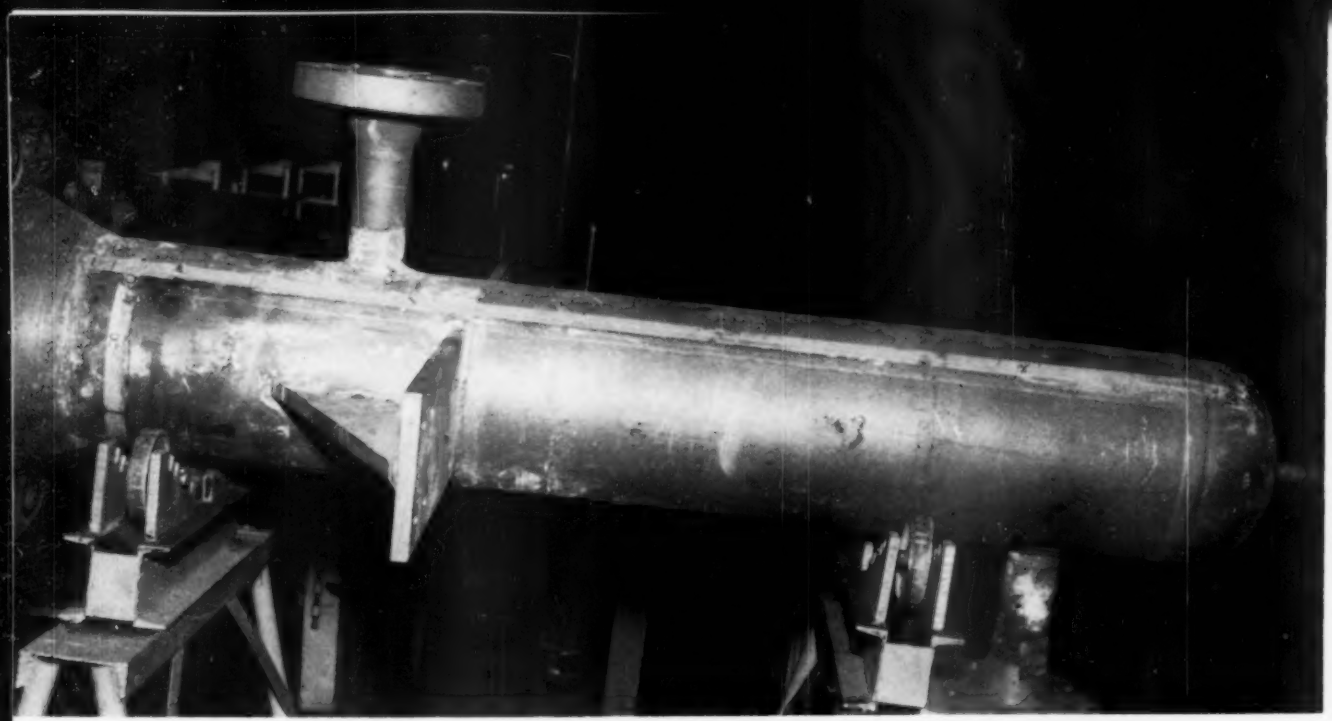

Fig. 1—Failed nuclear thermal-hydraulic experimental-loop vessel

Repair of Failed Nuclear Thermal-Hydraulic Experimental Loop Vessel

demands careful consideration of all factors involved. With such vessels, rigid attention must be given to the relation of possible service conditions to design requirements

BY E. B LaVELLE

General

A considerable amount of information is being sought in the field of high-pressure high-temperature service through experimental work being done with thermal-hydraulic loops. The failure of one heavy-wall stainless-steel vessel used for such service after 15 months of productive use indicates the need for a high order of fabrication quality control and for extreme care in all service conditions which might, conceivably, exceed the capabilities of the vessels or piping inherent to the pressure system.

Description of Vessel

Figures 1 and 2 illustrate the salient features of the failed vessel which was fabricated from Type 347 stainless-steel plate, approximately 1 in. thick, when completed. The purpose of the vessel was to preheat the process water before it passed through the test section. Process conditions required a preheat to 600° F. To attain this temperature, 100 kw was required in the one heater, with the No. 2 heater in the system to be used as a standby unit. To attain the required preheat, mineral-insulated heating elements were tightly packed into the vessel and sealed into the head flange.

It will be noted in Fig. 2 that the outlet nozzle is a considerable distance from the flange end, which was the uppermost part of the vessel when in operation. To avoid possible overheating in the part of the vessel above the outlet, the original design required a 22-in. cold section in the heating elements above the nozzle. This 22-in. cold section was reduced to 6 in. as the fabricator found it impossible to develop the required 100 kw with the 22-in. reduction in effective element length. This placed more reliance on turbulence and diffusion to transfer

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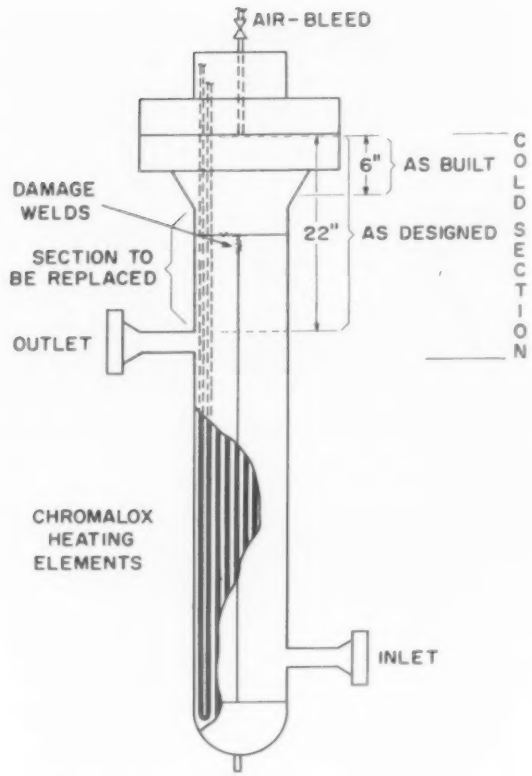


Fig. 2—Details of damaged vessel

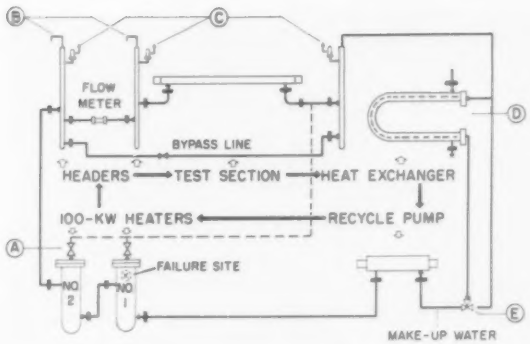


Fig. 3—High-temperature high-pressure loop

Fig. 4—Longitudinal cracked seam

heat away from the dome of the vessel and through the outlet nozzle.

Description of System

The thermal-hydraulic loop which contained this vessel as a component was designed to develop data regarding the behavior of a reactor system under certain pressures and temperatures.

Figure 3 illustrates this system which is a closed loop used to evaluate heat-transfer phenomena under high-pressure fluid flow. The apparatus functions in the following manner:

1. The recycle pump maintains a 150-gpm flow at pressures up to 2500 psi.

2. The two 100-kw heaters maintain the system water at 600–650° F.

3. Vertical headers distribute and control flow to the test section.

4. Through the test section, the preheated water flows annularly around an electrically heated rod supplying 100,000 to 400,000 Btu per hour per square foot of surface.

5. The water then flows through the heat exchanger where the heat picked up in the test section is removed before going to the recycle pump.

As originally installed, five features were included in the apparatus and system to protect against excessive pressures and temperatures. The circled letters designate these safeguards, as follows:

A. The heater covers were provided with bleeder valves to release accumulated air or gas after filling the loop and before heating the water.

B. The first two vertical headers also contained system high points and were provided with bleeder valves to release entrapped air or gas before startup.

C. All three headers were provided with pressure relief valves, starting upstream at about 2300 psi and set at decrements of approximately 100 psi to allow for pressure drop through the system.

D. A heat exchanger was installed to compensate for the heat gain in the test section.

E. A metering valve apportioned flow through the heat exchanger and the by-pass, thus permitting temperature control of the water returning to the recycle pump.

Operating personnel were further protected by the installation of the pressure vessels in a concrete trench below floor level. Associated piping which extended above floor level was enclosed within a heavy plywood barricade as an additional safety precaution.

Occurrence of Failure

On a routine startup of the facility, after 15 months' service, a hissing sound, like escaping gas, was heard after 4 hr of heating and the equipment

Fig. 5—Radiograph of cracked longitudinal seam

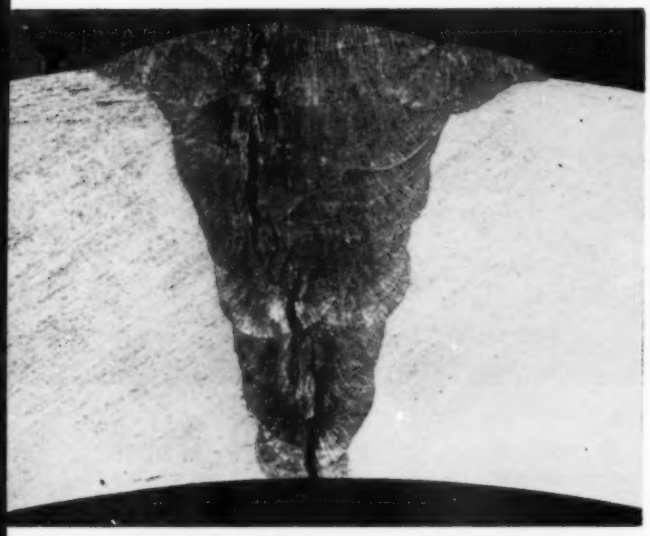


Fig. 6—Photomacrograph of cracked longitudinal seam

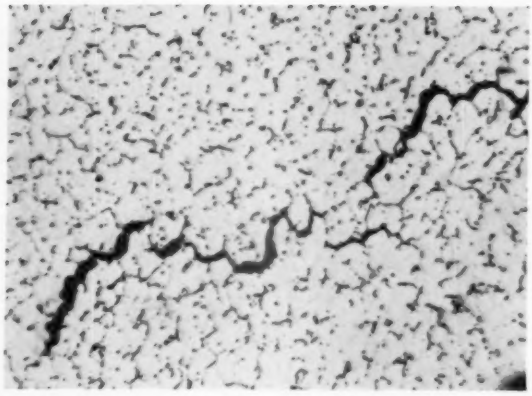


Fig. 7—Photomicrograph of microfissures in weld

Fig. 8—Radiograph of cracked circumferential seam

was immediately shut down. Inspection of the facility identified the system failure through a crack in a longitudinal weld in the No. 1 100-kw preheater. After the insulation had been stripped away, it was discovered that the whole shell section above the outlet nozzle noted in Fig. 1 was badly discolored from overheating.

It is obvious that an accumulation of air or gas in the dome above the outlet nozzle displaced the process water and permitted the exposed heating elements to overheat the vessel shell.

Inspection of Failure

Exterior view of failure in a longitudinal weld in the vessel shell is shown in Fig. 4, while a radiograph of the ruptured area is illustrated in Fig. 5 and a macrograph in Fig. 6. Subsequent metallurgical studies established the existence of numerous microfissures filled with nonmetallic material, shown in Fig. 7 as solid gray area in the fissures. This condition suggested the existence of these microscopic flaws at the time the weld was made. The manufacturer's original radiographs were obtained and compared with complete radiographs of both vessels after the failure. No indications of microfissures were found in any films, the techniques used being normal to industrial practice which do not ordinarily reveal microscopic fissures. No cracks were detected in any of the radiographs taken of the No. 2 preheater, although it, too, was discolored in the area above the outlet nozzle. Discoloration of the shell indicated that the temperature had greatly exceeded the design limit.

Numerous transverse fissures also occurred in the circumferential weld seam joining the weld-neck flange to the vessel shell. Because of the 1-to-2 ratio of stress in the circumferential direction as compared to longitudinal seams, it is not difficult to understand why, if the longitudinal weld failed in its axial direction, the transverse fissures occurred in the circumferential weld in the same direction. Therefore, it must be assumed that the weld metal had: (1) insufficient strength at temperature to withstand the imposed stress and (2) insufficient

ductility to redistribute stress without failure. A radiograph of some of the cracks occurring in this seam are shown in Fig. 8.

Had cracking been confined to the longitudinal seam alone, the repair would have been relatively simple, necessitating only removal of damaged weld metal and replacing with sound welds. However, because of the large number of cracks in a relatively small local area of the circumferential seam, it was necessary to remove a complete section of the vessel shell.

Sectioning of Vessel

After it had been decided that the vessel was to be repaired, it was necessary to remove the damaged section of the vessel shell. This was done by circumferentially sectioning the vessel at two locations, with the flux-injection cutting process. In retrospect it can be said that the sectioning operation should have been done by machining rather than by flame cutting for the following reason: although the line of cutting on the flange seam was well beyond the ends of the circumferential weld cracks as determined by radiography, apparently the heat of cutting caused an extension of the cracks into the flange neck. Probably this extension was a result of intensification of the stress which originally caused failure of the vessel and which had not been entirely relieved by the transverse cracking in the circumferential flange-to-shell weld. For a time it was believed that extension of the cracks into the weld-neck flange had ruined it; however, upon consulting Section VIII of the Boiler and Pressure Vessel Code it was confirmed that an alternate weld-neck flange geometry could be machined from the sound metal of the weld neck according to Fig. 6 (b) paragraph UA-48 (2), page 119, of the Code (1956 Edition). Details of this joint, prepared for consumable-weld insert, are illustrated in Fig. 9. Fluid penetrant testing of the machined surface, after the final geometry had been attained, indicated that all of the cracked material had been removed.

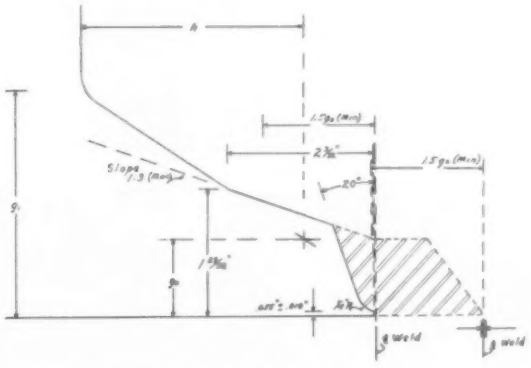


Fig. 9—ASME Code Par. UA-48(2), Fig. 6(b), joint

The circumferential flame cut on the vessel at the other end of the split longitudinal welded seam was made without difficulty. However, the weld areas were also tested with fluid penetrant to obtain assurance that sound metal had been reached.

After the cut had been made with flux injection, the end of the vessel was machined for a consumable-weld insert joint with U-groove form because of the thickness of the vessel shell.

Procedure Qualification for Shell Joints

No ASME Code procedure for making the longitudinal or circumferential joints with consumable-weld inserts existed at Hanford; so, these had to be developed. A Procedure Specification, HW-7185, supported by a Welding Procedure No. HW-7185-3 (shown in Fig. 10) was established by a Procedure Qualification Test Record HW-7185-A under the HAPO Welding Qualifier using the welder who was to do the repair welding, thereby avoiding the necessity for making a separate performance qualification.

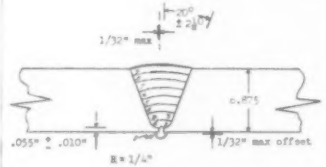
Only $^{7}/_{8}$-in. plate was available for qualification testing. Thus it was necessary to establish two additional welding procedures to cover the repair work itself, one for the longitudinal joints in the $1^{1}/_{4}$-in. plate which was used as the replacement section.

HANFORD ATOMIC PRODUCTS OPERATION
GENERAL ELECTRIC
RICHLAND, WASHINGTON

WELDING PROCEDURE

Pipe or Plate
Austenitic Stainless Steel, Type 304L
Inert-Gas-Shielded Tungsten-Arc for Closure Pass and First Two Fill Layers
Shielded Metal Arc for Succeeding Fill Layers
Single-U Butt Joint
Type 308L EB Consumable Weld Insert
Type 308L Bare Rod for First Two Fill Layers
E308L-16 Electrode for Remainder of Fill Layers

Vertical Fixed Position
0.875-in. Thick Material



Postheat 1550 F for one hour

QUALIFIED UNDER PROCEDURE TEST RECORD NUMBER -	HWS-7185-A	DATE	6-2-58	BY (WELD QUALIFIER)	L. H. Rasmussen

SEE WELDING PROCEDURE SPECIFICATION NO. HWS-7185 FOR QUALITY REQUIREMENTS.

PROCESS VALUES					
DIRECTION OF WELDING	LAYERS	GAS	GAS FLOW	AMPERAGE	WELDING ROD SIZE
Reading	1st	Argon	20 CFH	85	Type 308L EB Weld Insert
Weaving	2nd and 3rd	"	" "	80	Type 308L 1/16" dia. Electrode
"	4th thru 9th	" Electrode dia. 1/8"	Voltage 22	110	" Type 308L-16

THIS PROCEDURE was prepared from data supplied by L. H. Rasmussen, J. A. Jones Construction Co., on 6-2-58

PREPARED BY F. B. LaVelle

APPROVED FOR HANFORD ATOMIC PRODUCTS OPERATION E. B. LaVelle HAPO CODE ENGINEER 6-2-58 DATE

ORIGINAL ISSUE
REV. NO.
REV. NO.
REV. NO.

PROCEDURE NO. HWS-7185-3

Fig. 10—Welding procedure HW-7185-3

and the other for the 1-in. circumferential welds which joined the replacement section into the vessel. Welds were to be made in the vertical or upper-quadrant of the joint; so, qualification on the $^{7}/_{8}$-in. plate was made in the vertical position.

Forming and Welding of Replacement Section

To provide adequate material for outer- and inner-surface machine cleanup in the replacement section, a $1^{1}/_{4}$-in. thick ASTM A167, Type 347 stainless-steel plate was used. This plate was cut oversize, press hot-formed in half sections and welded longitudinally, using weld-insert joints. The closure was made with inert-gas-shielded tungsten arc and the grooves filled with shielded metal-arc welds, using a welding procedure for $1^{1}/_{4}$-in. thick material. Closure pass as well as one-third, two-thirds and final welds were fluid-penetrant inspected, then radiographed and found acceptable. The section was then machined on both *ends* of the inner and outer surfaces to conform with the profile machined on the weld-neck flange and the undamaged vessel section. The replacement section was then ready for welding into the vessel.

Alignment and Support Fixture for Replacement Section

A condition of final repair was that the interior of the vessel be completely smooth to provide for the large number of mineral-insulated heating elements with which the vessel was to be packed. Because of the necessity for joining with precise alignment the old vessel section, the replacement section and the weld neck flange, a special holding fixture was fabricated to attain optimum smoothness. This is illustrated in Fig. 11.

It was not necessary to take loss of dimension through weld contraction into consideration because the heating elements were somewhat shorter than the over-all inner vessel length. This being so, it was necessary only to support adequately the several sections to attain precise axial alignment of the completed weldment. After tacking had been accomplished, fusion of the weld inserts was done. Inside of the vessel bore, showing closure welds before machining, is pictured in Fig. 12. Restraint offered by the holding fixture was adequate to resist any tendency of the closure welds to disturb the axial alignment. After the inert-gas-welded closures had been completed, the weld grooves were filled with shielded metal-arc weld metal in accordance with the 1-in. material thickness welding procedure. Individual weld layers were deposited in several steps along the joint to avoid excessive stress concentration at any one point, with the thought that, by so doing, any slight tendency toward angling of the joints would be avoided. Completion of the two circumferential weld joints left the vessel sections in perfect alignment and it was then removed from the fixture. A fly-cutter machine operation was used to remove the slight inner uniform weld reinforcement which resulted from fusing of the weld insert, as well as the inner surface of the replacement section which was purposely left undersize to provide for the final machine operation. Interior surface prior to machining is shown in Fig. 12. Exterior surface was then machined to proper diameter.

Postheat Treatment (Stress Relief)

After welding and final machine work had been completed, the vessel was stress relieved at 1550° F for $1^{1}/_{2}$ hr. The welds were then radiographed in accordance with Par. UW-51 of the Code. A very few minor imperfections were found but these were not removed because of their relative insignificance. Paragraph UHA-33 (c) of the Code now requires that radiography be done *after* stress relief and this was accomplished.

The companion vessel was coincidentally stress-relieved, radiographed and hydrostatically tested and judged acceptable for further service.

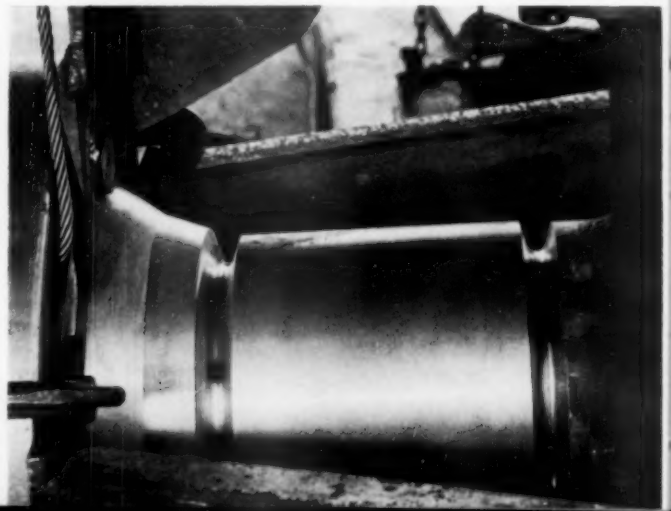
A hydrostatic test of 4700 psi, which is $1^{1}/_{2}$ × design capability plus temperature correction for Type 347 stainless steel at 600° F, was performed.

Documentation

Documentation of repairs was accomplished by establishing for the record a National Board Repair report, signed by the third-party inspector. Supporting the NB Report were the following:

1. Statement of necessity for repairs to vessel.
2. Identification records pertaining to the added Type 347 stainless steel plate substituted for the damaged section.
3. ASME Code Procedure Specification covering the repairs.
4. Welding Procedures covering qualification test and the 1 and $1^{1}/_{4}$-in. thick welds.
5. Procedure Qualification Test Record (also is Performance Record for one welder).
6. Identification relating to consumable-weld inserts, bare filler rod for inert-gas-shielded tungsten-arc layers and shielded metal-arc electrodes.
7. Stress-relief record.
8. Radiography report.
9. Hydrostatic-test records.

Fig. 11—Joint-holding fixture



10. Sketch of the Code joint profile to which the weld-neck flange was machined.

Manufacturer's data plate was replaced on the repaired vessel after testing had been completed.

The vessel was National Board registered with a separate manufacturer's plate attached. This plate was attached to the damaged section and there was considerable discussion with the third-party inspector as to whether the vessel should be repaired with National Board repair documentation or by using the old manufacturer's data report as a "Partial Report," considering the final fabrication as a "new" vessel. An additional complication was the fact that the vessel shell (after sectioning) was found to be somewhat less thick than the "shell thickness" stamped on the manufacturer's plate, although a capability calculation using the actual shell thickness showed the pressure-temperature rating of the

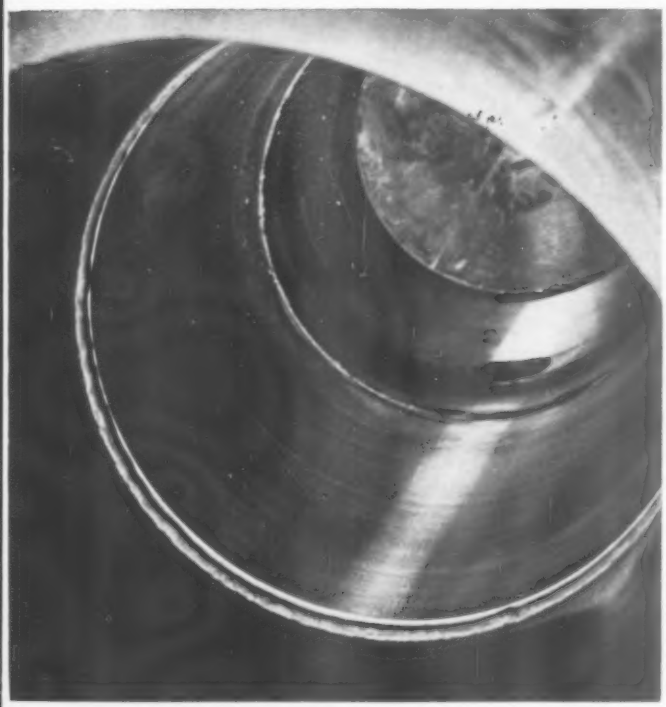


Fig. 12—Interior of vessel

vessel to be valid. On the basis of the complications which would be inherent to getting these matters reconciled and to avoid the substantial correspondence which would be involved, it was decided to document the work as a National Board repair. The nameplate was removed from the damaged shell section and was reaffixed to the replaced section after repairs and testing were complete. A stamped notation was made on the vessel that the nameplate had been transferred, together with the date of transfer.

Discussions Related to Causes of Vessel Failure

The original pressed half-shell sections were not stress relieved after forming and it is assumed the welding may have left so much concentrated outer-fiber stress in the weld areas that the incidence of the high temperature transmitted from the exposed heating elements was ample to cause plastic movement and failure in the fractured area. In view of the failure, it was decided that the companion vessel, preheater No. 2, should be stress relieved, radiographed and hydrotested. This was done and no defects requiring removal and repair were noted. Preheater No. 2 was then judged satisfactory for continued service.

Reinstallation of Preheaters

When reinstalled, the valves for manually bleeding off entrapped gas or air at the heads of the preheaters were supplemented by a continuous bleed line which extends from the preheaters to a point downstream from the test section, as indicated by the broken line in Fig. 3. The pressure drop of over 300 psi through this part of the system provides for a continuous flow through the bleeder line. Thermocouples were mounted on the vessel shell at the head flange, the girth weld and the outlet nozzle to obtain assurance that metal temperature is not unduly high and that continuous bleeding is effective in removing entrapped gas. Temperatures within the design range are being maintained in service, which establishes operation within safe limits.

Conclusion

It is evident that adequate design and operational considerations must be given complete attention in order to obtain assurance of satisfactory performance when exposed to service conditions; further, that no design changes should be made without consultation with the original designers of the vessel. In this instance, had the original cold section been maintained, the vessel would not have become overheated; had there been continuous and adequate water bleed from the dome section, any gas in the liquid would not have been entrapped and the hot elements would not have been exposed so that their radiance would overheat the vessel shell.

Acknowledgment

Grateful acknowledgment is extended to Russell H. Scott of Hanford Laboratories Operation, General Electric Co., for his valued assistance with preparation of this paper and to the Photography Operation, Construction Engineering and Utilities Operation for the illustrations which support the text.

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Complex Steel Weldments

Twin 90-ft-diam mobile radio telescopes, weighing 175 tons each, require special precautions in shop and field assembly

BY J. AUGUST RAU AND WILLIAM F. FISCHER

Latest concepts of precision arc welding, stress relieving, testing and inspection contributed to the successful building of twin mobile radio telescopes, weighing 175 tons each and equipped with 90-ft-diam parabolic dishes or antennas, now being operated in the Owens Valley desert near Bishop, Calif., by the California Institute of Technology. They stand some 90 ft high and the open-mesh reflectors can be focused on any point in interstellar space above the horizon through electric drive, gearing and counterweights. The project involved expenditure of $1.5 million, supplied principally by the Office of Naval Research.

Fig. 1—Close-up of carriage, conical base, pedestal yoke and welded tubular-steel radial truss work supporting the 90-ft-diam radio telescope mesh screen

General contractor was the Allison Steel Mfg. Co. which produced most of the basic weldments in its shops at Phoenix, so that a minimum of welding had to be done in the field. Principal elements are a wheeled carriage and base riding on tracks 35 ft apart and 1600 ft long; a pedestal and yoke; declination tube and polar axis shaft; large roller bearing mounts, and the 90-ft-diam dish carried on a framework of 4-in.-diam tubing in the form of radial trusses. Close-up of the supporting structure and part of the dish are shown in Fig. 1.

Details of Construction

The base comprises a structural framework mounted on wheel-truck assemblies designed to carry on over-all dead weight of about 175 tons. Accurate alignment and leveling are by means of hydraulic jacks and mechanical screws. Fabrication was handled in the shop, with weldments as large as could be shipped. Stress relieving of the carriage weldments was done at 1100 to 1200° F, 1 hr for each inch of section thickness, except on alloy steels. Rate of heating did not exceed 400° F per hr, divided by the section thickness. Pieces were furnace cooled to about room temperature. They included carriage ends, gear boxes, gears and upper pedestals.

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Carriage ends embody plate thicknesses up to 3 in. Figure 2 shows one as delivered to erection site.

The pedestal and yoke structure is primarily of $^3/_8$- and $^1/_4$-in. plate with heavy internal stiffening members up to $1^1/_2$ in. thick. All complicated intersections of members were planned for check assembly in the shop, followed by disassembly into maximum-size shipping pieces for subsequent field reassembly and welding there.

The pedestal-yoke assembly involved critical fabrication accuracy and later had to be precision bored for the large self-aligning roller bearings used in mounting the polar-axis shaft. Stiffening members on the interior of the pedestal were so complex that little space was left for assembly and welding, all of which demanded careful inspection and supervision. All welding was carried out under AWS structural certification, and all welders were selected meticulously for certification in all positions for these complex weldments.

Gear boxes and drive mechanism, other than the small, fractional horsepower motors, were designed specially for heavy plate weldments which, after stress relief, were precision machined and fitted with close-tolerance gearing supplied by the subcontractor, Keystone Engineering Co., Los Angeles. Gear boxes and drives completely fill the top levels of the pedestal interior. Actual bearing mounts are of weldable low-carbon electric steel castings, fully stress relieved.

The massive declination tube, shown in process of erection on the upper pedestal yoke in Fig. 3, is a cylindrical weldment of $^3/_8$- and $^1/_4$-in. plate, including stiffener and bearing assembly plates up to 2 in. thick. It was designed so that it could be assembled and aligned from the polar-axis shaft with a minimum of rotational deflection. Ends of the declination tube are fitted with primary gear boxes, again made from steel weldments, stress relieved, machined and fitted with high-tolerance gearing. The tube ends support the dish-bearing hubs by means of adjustable hollow forged-steel shafts, so arranged as to permit accurate alignment in the field.

All of the large gearing was custom made from welded designs for this particular project. In general, it comprises solid webs and hubs of ASTM A-373 quality steel. Gear blank material includes both FS 4130 steel, preheat treated to a minimum yield point of 103,000 psi and, on larger gears, T-1 steel, heat treated to the same yield point.

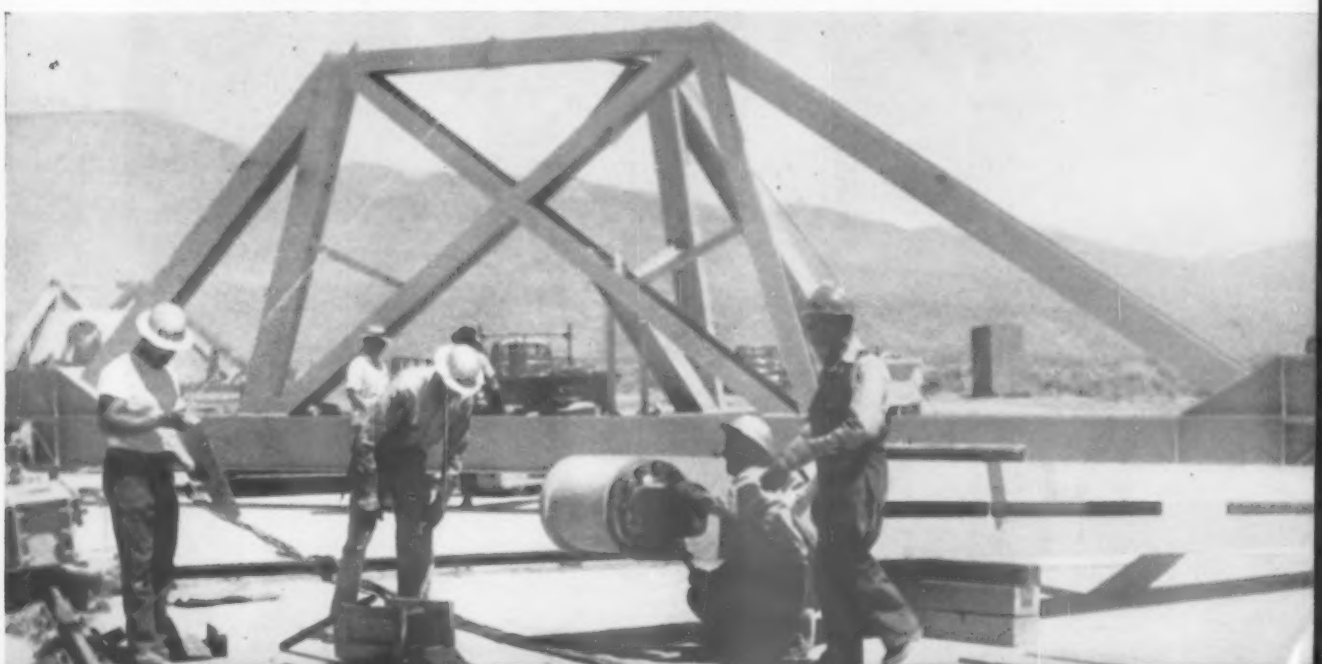
Large sector gears, of T-1 steel, include four assemblies, each with an inside radius of 5 ft $5^1/_2$ in. inside the gear blank and a gear blank $3^1/_2$ in. thick and 7 in. wide. This blank was cold formed to radius and then forcibly clamped to the previously stress-relieved web and hub section. While held in close mechanical fit-up and contact, the joint was welded with dual balanced heat input to the 1-in. web plate. Electrodes for this work were low-hydrogen AWS E-6016 class.

This welding operation was most critical and, as mentioned, was carried out in a balanced-heat arrangement, with two operators working directly opposite each other. The steel was held at a preheat level of 300 to 400° F and after welding was fully stress relieved at 900° F or slightly below the draw temperature of the heat-treated gear blank.

Support for Scanning Dish

Base structure, pedestal and yoke, declination tube and bearing-mounting systems are all required to support and direct the position of the 40-ton scanning or receiving dish. The latter, with its counterweighting system, is the most important element of the 'scope from a structural and dimensional tolerance point of view. Function of the dish is to receive radio waves from a selected point in

Fig. 2—Part of the base carriage end weldment as shipped to the site after shop welding. Complete carriage rides on tracks 35 ft apart, and is designed to support 175 tons



interstellar space, focus them to a central collecting post which funnels the impulses to amplifying equipment in a ground station. There the signals are transferred to pen recorder, oscilloscope or magnetic tape for interpretation. The dish is designed to collect and focus radio wave lengths from 0.4 to 2 in.

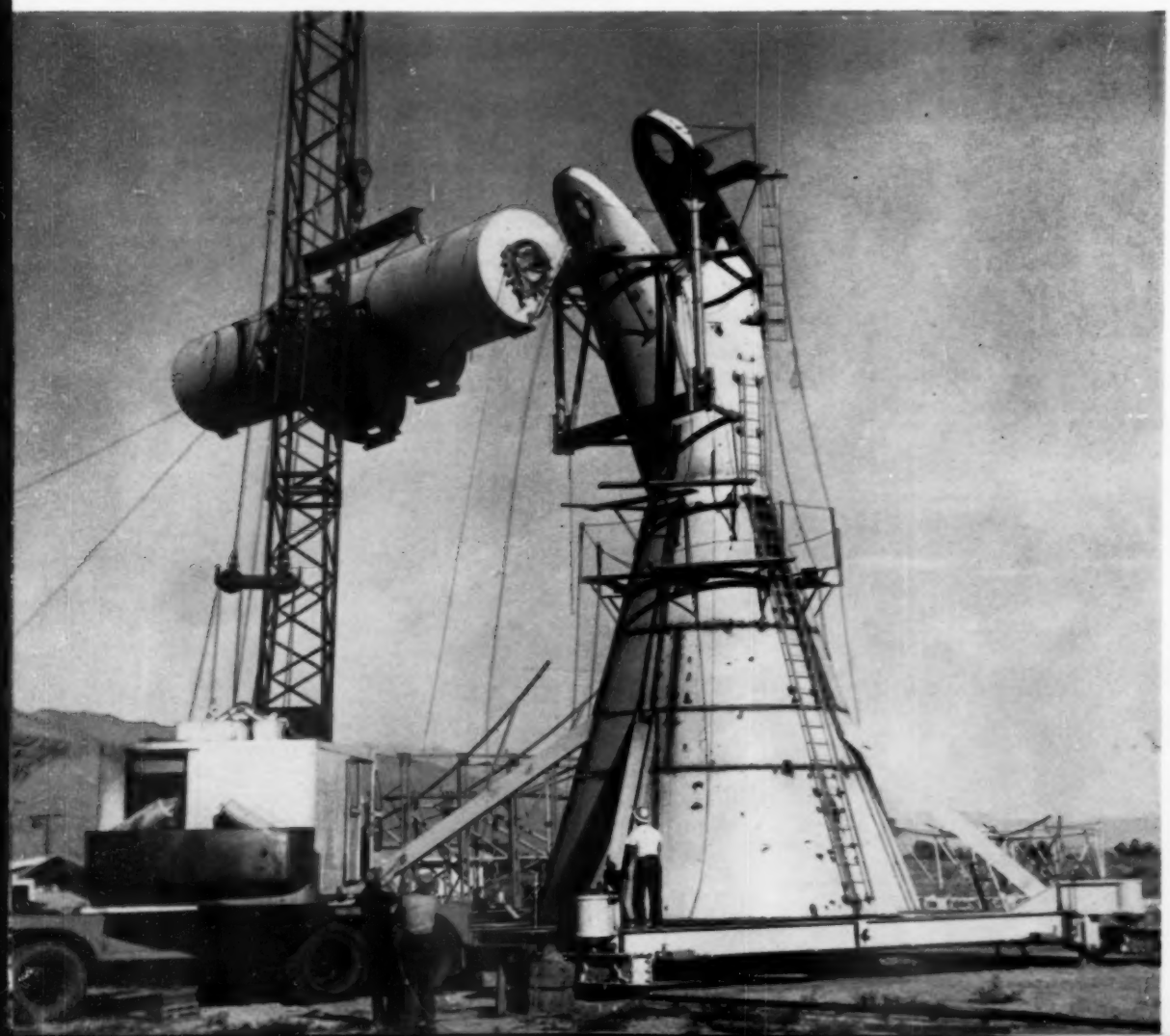
The 6400-sq-ft expanded-steel mesh surface of the dish is supported by 324 adjusting screws carried by a complex framework of tubular-steel radial trusses. To meet demands of strength and accuracy, it was decided to build a special milling machine and fixture for precision milling of all tubing intersections on primary shop weldments, to provide a tight mechanical fit-up. This proved of great value in minimizing shrinkage and locked-in stresses. Close-up of the machine in operation is shown in Fig. 4.

The radial tubular trusses were contoured carefully and set up in an accurate jig frame that controlled the curvature of the inside parabolic alignment to plus or minus $^{1}/_{16}$ in. A complete triangulation truss system was clamped together prior to welding and held in the jig until fully tack welded. The tubing for the most part is 4-in. OD cold-rolled electric butt-welded section produced from a strip of FS-1020 carbon steel with wall thickness of 0.120 in. These members are used predominantly except at major stress-concentration points where the wall thickness was increased to 0.318 in. These heavier tubes are attached to steel castings which serve as bearing mounts for the large roller bearings with OD of 32.2835 in. and ID of 22.0472 in. Shop welding of heavy tubing to a bearing mount is illustrated in Fig. 5.

To insure minimum dimensional deflections, the designer decided it would be advisable to fabricate all critical hub sections and radial trusses in shop jigs, some of which were erected in an outside yard on concrete bases and pedestals to simulate their later relative position in the structure itself.

Typical tubular joints also were duplicated, full size, and after welding were sent to Cal Tech laboratories where they were tested to destruction to determine the efficiency of the welded intersections. Following the tests, it was determined that chamfer.

Fig. 3—Spectacular field assembly of the welded-steel declination tube into the upper pedestal yoke. It is a cylindrical weldment of $^{3}/_{8}$- and $^{1}/_{4}$-in. plate, stress relieved



ing the edges of all tube ends was necessary to develop the proper weld-metal penetration and the full-thickness values of the tubes.

Counterweights for the dish are unusual. Two are required, one directly below each of the large bearing hubs, with center of gravity as close to the structure as possible and still provide clearance for low-level observations, that is, with the dish elevated on its declination tube to near-vertical position. Each counterweight comprises four solid-steel blooms of weldable-quality steel assembled into a mass 32 in. square and about 11 ft long, weighing 19 tons. They were positioned in a shop jig for skip welding the blooms together and for connecting the struts which attach to rotational support hubs. One of the counterweights is shown in Fig. 6, with trim-weight plates attached to the end.

Special assembly frames were designed and fabricated for accurate parabolic assembly of the components to the finished dish in the field. This assembly was handled by the field subcontractor, American Corp., Los Angeles. The actual skin of the antenna surface was designed for complete shop fabrication into a series of segments, each made as a weldment and each contoured to its particular part of the surface. The segments were warped to contour in their respective framing members and held closely to position in welding jigs. While in the jigs, the screen surface of $^1/_2$-in. 18-gage expanded-steel mesh was welded into place with $^1/_{16}$-in. diam AWS class E-6010 electrodes. Use of the expanded mesh permits wind to penetrate the large arc and also allows rain to pass through. Gales as high as 80 mph are encountered in the desert area, although the 'scopes are never operated when wind velocity exceeds 25 mph. There is a limit to the length of hole permissible in the mesh surface in order not to interfere with receptivity.

Each dish segment has a means for corrective alignment of the skin through catenary pull wires on the reverse side, and also is equipped with a system of adjusting screws so arranged that a man can walk on the surface of the dish and insert an adjusting wrench to move any of the 324 support points either inward or outward to maintain parabolic alignment within the required $^1/_{16}$ in.

Fig. 4—Special milling machine with adjustable fixture was developed to precision mill the intersections of 4-in. diam dish support tubes for good fitup before welding

Fig. 5—Complex details of shop assembly and welding of 4-in. truss tubes into dish bearing housing. Tube ends are chamfered for good weld-metal penetration

Additional Details on Installation

Some further pertinent notes on the installation: The telescopes are the largest in the U. S. west of the Mississippi and mark a further major step in progress of the 10-yr-old science of radio astronomy. The technique is further advanced in Australia, England and the Netherlands. English scientists, for example, are operating a radioscope 250 ft in diam.

The track on which the telescope is moved by tow trucks is 1600 ft long. Eventually, two tracks will be operated, one running east-west and one north-south. When sighting on a target area, weight of the 175-ton instrument is transferred to steel caissons sunk 16 ft into the ground at stations alongside the tracks. It is planned to "team" the two 'scopes for use in interferometer measurement techniques.

Two large declination drive gears attached to the structure are $11\frac{1}{2}$ ft diam and weigh over 9000 lb each. The gears must mesh with their respective pinions to within 0.005 in. at each tooth along the entire 18-ft periphery of the gear sector. Two other gears of the same large diameter and weighing 7500 lb each are called "hour angle drive" gears. They move the antenna at exactly the same angle and speed as the rotation of the earth but in the opposite direction, so that the "ear" will always be tuned to the same spot in interstellar space.

Choice of the desert site was dictated by the fact that adjoining mountain ranges provide protection from man-made radio and electrical interference.

As a concluding observation, scientists admit the 'scopes could be used to track space vehicles, but they consider this application "unlikely."

Fig. 6—In the foreground is 19-ton welded counterweight, comprising four steel blooms, as prepared for shipment. In the background is one of the dish bearing enclosures

Charles W. Jones, Engineer of Los Angeles, prepared the design and contract drawings to meet the requirements of the Radio Astronomy Division of The California Institute of Technology.

Hard Surfacing Lengthens Service Life in Continuous Centrifugal Filtration Machine

The solid bowl centrifugal coal filter manufactured by Bird Machine Co., South Walpole, Mass., is frequently required to process abrasive materials. Where the end use is known to be abrasive, Bird solves the wear problem by hard surfacing the screw-conveyor components most subject to abrasive forces.

The function of the conveyor is to continuously convey separated solids from the centrifuge in the machine while exposed to centrifugal force. The pressure of the solids against the discharge blade (helix) due to centrifugal force is considerable. To reduce the rate of wear, hard-surfacing overlays are applied to the working face of the conveyor helix and to the feed ports in the conveyor hub (Fig. 1).

The hard-surfacing alloy most frequently used by Bird for this purpose is type RNiCr-C, a nickel-base material containing chromium borides as well as the conventional chromium carbides for wear resistance. This alloy, used in rod form, has gained favor for three reasons: (1) it is easy to apply; (2) it is corrosion resistant; and (3) it is less costly to use.

Ease of application is inherent in type RNiCr-C alloy because it is applied at relatively low temperatures. Applied by welding with the flame of an oxyacetylene torch, a hard, smooth overlay is readily produced. It has good flowability at all temperatures, providing easy control of the deposit as applied. A uniform overlay of specified thickness is, therefore, more easily achieved.

Type RNiCr-C alloy possesses inherent corrosion resistance, providing good performance even when exposed to the variety of conditions and elements, all the way from pure acid to pure alkaline, encountered in mining operations.

The economy effected with RNiCr-C is due largely to its ease of application. Time required for welding is less, resulting in lower labor costs. Savings in material too, are realized because of the better deposit control; the overlay is more easily and uniformly controlled with regard to desired thickness as well as finished appearance. Thus, less alloy rod is required for a given surface area.

The screw conveyor is hard surfaced from the edge of the flight on the pressure side (in contact with the material conveyed). The distance from the edge and thickness of overlay varies with different types of service, but ordinarily the overlay extends about 2 to 4 in. from the edge (Figs. 3, 4). The welded deposit usually varies from $^{3}/_{32}$-to $^{5}/_{32}$-in. thick. The back corner of the flight is beveled at 45 deg to provide narrow bearing on the cake (compacted material) and thus reduce power consumption due to friction.

Based on a story by Wall Colmonoy Corp.

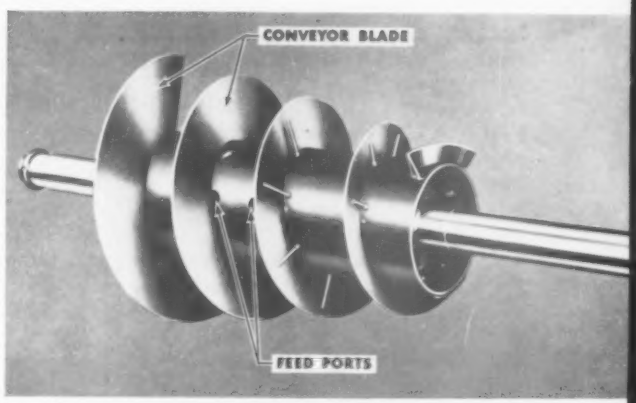


Fig. 1—Conveyor screw for solid bowl centrifugal coal filter is hard surfaced on feed ports and leading edge of conveyor blades to minimize wear

Fig. 2—Using recommended gage to check wear on conveyor blades

Despite the unusual wear resistance of the hard-surfacing overlay, wear in service will occur. Blades are checked for wear with a gage of the type shown in Fig. 2. In service the screw flight should not be allowed to wear more than $^{3}/_{8}$-inch. When a gage check reveals wear between $^{1}/_{4}$ and $^{3}/_{8}$ in., the flights should be rebuilt by overlaying to original dimensions with RNiCr-C alloy rod.

Surface Preparation and Application

The area to be hard-surfaced should be clean and free of grease, rust or scale. A portable hand grinder is the best tool for this purpose. Special care must be taken to clean the weld area where flight segments are joined together.

After the flight surface has been thoroughly cleaned, it should be preheated to about 600°F.

Conveyor flights are fabricated of medium carbon-steel plate $^1/_4$-in. thick. A neutral flame should be used; procedure is similar to torch brazing in which the overlay is tinned to the base metal, except that no flux is required. Care must be taken to avoid oxidation of the base metal ahead of the overlay; back-hand welding is the best method. The RNiCr-C rod will run out leaving a smooth deposit which requires no grinding or other sort of finishing on the overlaid surface. The 45-deg bevel, of course, must be ground. Grinding is best accomplished using a green silicon carbide wheel–hardness H to K–24 to 36 grit.

To obtain the smoothest deposit, the bead should be laid from the periphery of the screw toward the center to join with the original hard-surface deposit. In other words, the welding pass is made across the screw flight instead of in narrow beads in the direction of the screw flight (see Fig. 3).

When wear is detected before it exceeds $^3/_8$ in., the flight can be built up to original dimensions by welding with the RNiCr-C hard-surfacing rod. Figure 4 shows a section through a new flight and a section through a worn flight which has been reclaimed by hard surfacing.

Should wear exceed $^3/_8$ in. on the screw flight, reclamation can be accomplished by first welding on a strip of steel plate to bring the flight to proper height. The repair strip should then be hard-surfaced in the same manner as outlined for the new flight (see Fig. 4). The Fig. 5 sketches show repair of a flight that has exceeded $^3/_8$-in. wear.

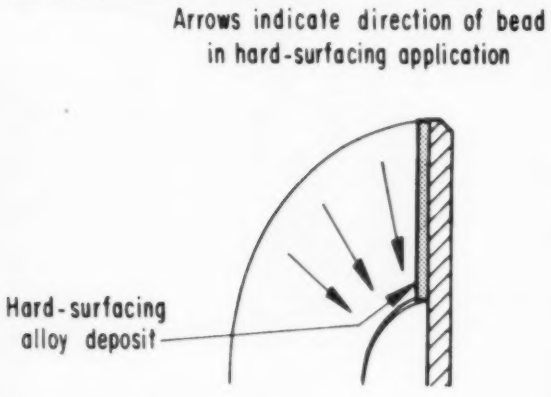


Fig. 3—Section through flight

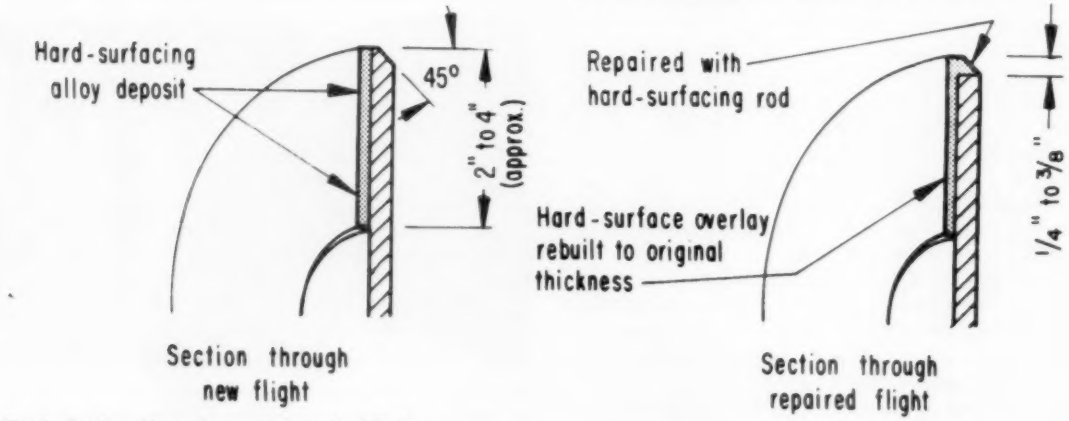


Fig. 4—Sections through new and repaired flight

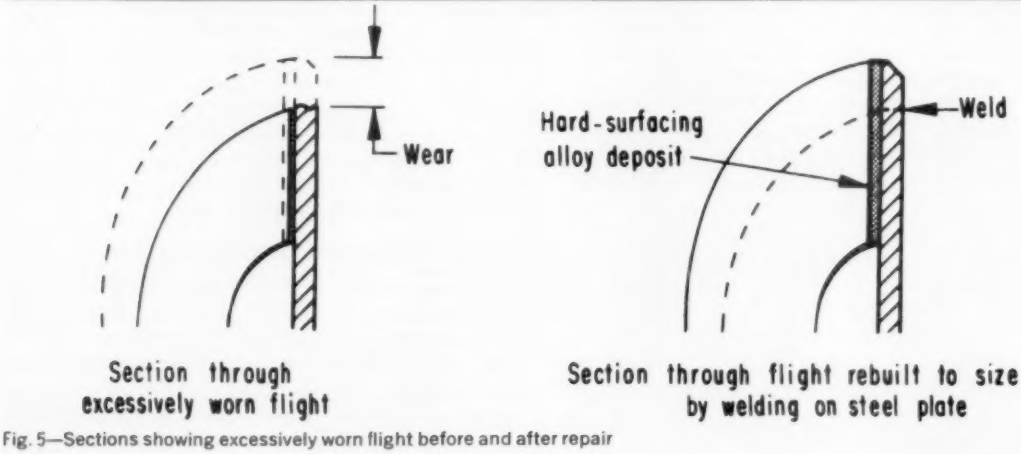

Wear
Section through excessively worn flight
Hard-surfacing alloy deposit
Weld
Section through flight rebuilt to size by welding on steel plate

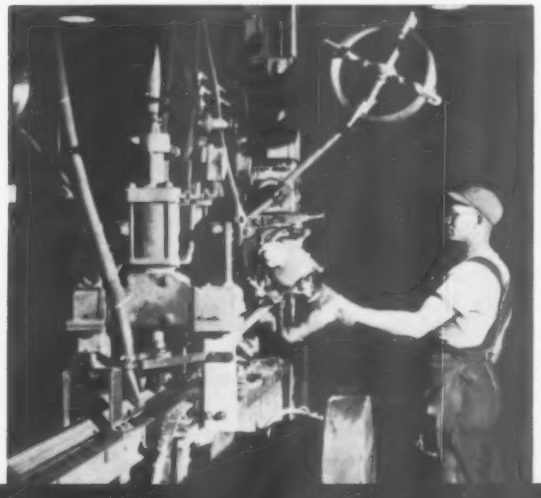
Fig. 5—Sections showing excessively worn flight before and after repair

Fig. 1—This modern plow, still the farmer's basic tool, is fabricated at Canton Works of International Harvester Co.

Fig. 2—Submerged-arc parallel welding fabricates plowshares at this automatic fixture, resulting in substantial cost savings

Fig. 3—CO_2-shielded magnetic-flux arc welding is used to fabricate breakaway-beam plow brackets at high speed

Fig. 4—Two steel angles form the plow's square-pipe main frame. As the angles pass between twin submerged-arc heads, both seams are welded simultaneously. Welding speed varies, and is either 38 ipm on $^3/_{16}$-in. pipe or 29 ipm on $^3/_8$-in. pipe



Age-Old Plow Goes Modern

BY J. J. SULLIVAN

Mechanization in our age has come a long way, but the plow and the means to pull it remain as the farmer's basic tools. The ox and the horse have long since given way to the tractor, and the plow of yesteryear has also been modernized.

These days, the Canton Works of International Harvester Co., Canton, Ill., is turning out the latest in advanced plows (see Fig. 1) with the help of semi- and fully automatic welding equipment. For example, in the production of breakaway-beam plow brackets and nearly one hundred different production items, the semiautomatic magnetic-flux CO_2-shielded welding process has produced consistent cost savings over previously used manual welding methods (see Fig. 3). Magnetic flux welding has proved most valuable in the heavy, hard-to-weld applications, and in joining high carbon to low-carbon steel.

Automatic submerged-arc welding also has found extensive use at Canton Works. Plowshares are fabricated in a parallel submerged-arc welding installation running at 775 amp (see Fig. 2). This installation has resulted in a substantial cost reduction over the previous method.

In another parallel welding installation, pairs of small channels are welded to form breakaway plow beams. The channels vary in wall thickness from $^3/_{16}$ to $^5/_{16}$ in., and are sandblasted prior to welding. Twin $^3/_{32}$-in. carbon steel wire is used with Grade 50, 8 x 48 composition, at 400 amp and a welding speed of 28 ipm.

Main frames are made of either $^5/_{16}$ or $^3/_8$-in. thick square pipe. Two submerged-arc welding heads weld the steel angles together along both seams simultaneously. The $^3/_{16}$-in. pipe is formed at a welding speed of 38 ipm, and $^3/_8$-in. pipe is formed at 29 ipm (see Figs. 4 and 5). Amperage used is 350, while 33v are used to smooth out the weld bead.

These high-speed welding processes for mild and carbon steel have helped International Harvester boost plow production and significantly reduce costs.

J. J. SULLIVAN is a Welding Sales Engineer, Linde Co., Chicago, Ill.

Fig. 5—Close-up view of the twin-head installation shown in Fig. 4.

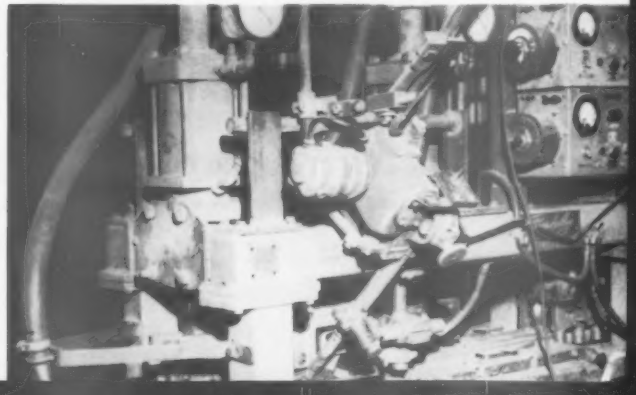


Fig. 1—Operator applies deposit of cobalt-base alloy to valve seats using a five-spindle hard-surfacing machine. This procedure reduces production time and cuts cost 48%

Mechanized Hard Surfacing Cuts Cost 48%

A five-spindle hard-surfacing machine has cut production time and reduced costs 48% for Okadee Co., Chicago, Ill. This machine is used to apply two cobalt-base alloys to valve seats and disks destined for exposure to corrosion, erosion and wire-drawing action during service.

The machine hard surfaces 30 valve seats per hour as compared to 16 seats per hour when manual methods were used. In addition, the five-spindle machine—with preheating, hard surfacing, postheating, cooling and loading stations—gives flat, uniform deposits requiring less hard surfacing alloy and less grinding time.

These hard-surfaced valve seats and disks are used in $^{3}/_{4}$-in. gate valves that control the flow and pressure of materials such as butane, propane and steam in coke ovens. The seats and disks are exposed to temperatures up to 800° F. and pressures of 720 psi.

The seating surfaces of these valve parts are grooved out and hard surfaced with a $^{3}/_{32}$-in. thick deposit of E-CoCr-C or ECoCr-B alloys using 3-ft lengths of $^{5}/_{16}$-in. diam bare cast rod. The desposit is finished to a depth of $^{1}/_{16}$-in. and lapped within $^{1}/_{3}$ of a light band.

The hard-surfaced exterior is tough and durable,

Based on a story by Haynes Stellite Co., New York, N. Y.

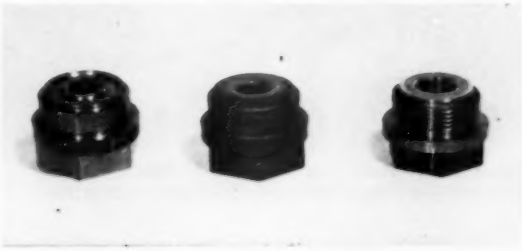


Fig. 2—Seat on the left is grooved out, ready for $^{3}/_{32}$-in. deposit, as seen in the middle seat. The seat at the right has been ground and is ready for service

giving lasting service. For example, 269,000 cycles of operation with propane showed no signs of seal failure. The deposit provides bubble tightness—a requirement in these $^{1}/_{2}$- to 10-in. nonlubricated, carbon-steel valves. Minimum hardness of the hard-surfaced parts is Brinell 430 for seats and 490 for disks.

Mechanized oxyacetylene hard surfacing has proved to be most effective in applications where very close deposit control and minimum deposit dilution are desired. These two advantages are combined with the high-production capability available through mechanization.

Society News

National Fall Meeting at Pittsburgh to Present New Findings

The 1960 National Fall Meeting to be held Sept. 26th–29th at the Penn-Sheraton Hotel, Pittsburgh, Pa., will cover the latest developments in research and application in the welding field. Of particular interest this year are the findings related to a number of problems in structural design and construction. The modern trend toward the use of higher-strength steels in structures underlines the importance of the structural presentations, some of which are sponsored by the American Society of Civil Engineers and the Column Research Council of the Engineering Foundation. Many other subjects of welding interest will be presented over the 17 sessions covering, in all, 51 papers. The program was printed in the June issue of the JOURNAL.

Other events of social and technical interest will abundantly fill the week's schedule. Highlighted among these is the opening day address by C. M. Parker, vice president of American Iron and Steel Institute, who will talk on the value of a technical society as a leader in education and research. Mr. Parker is well qualified to develop this timely and important topic. He has been intimately connected for many years with the work of numerous AISI committees on research and steel technology and presently heads up this branch of his society. He has brought out before the public the results of many studies by publication of numerous articles in trade and professional journals and is the author of several books. He has been an active consultant on many government advisory committees including the National Bureau of Standards and the National Research Council.

During the week, plant tours will be made to the Shippingport Atomic Power Station of the Duquesne Light Co., the American Bridge Co. at Ambridge, the New Kensington Works of Alcoa and the Brackenridge Works of Allegheny Ludlum Steel Co.

An interesting Ladies' Program is being arranged to provide visits to places of unusual attraction or historical distinction.

Among other noteworthy features of the program will be a midweek luncheon for which a well-known speaker is to be invited. Regular committee meetings will be held during the week, as well as the meeting of special groups. On Monday, September 26th, an RWMA committee meeting and luncheon is scheduled. On Tuesday the Districts Council breakfast

C. M. Parker

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meeting and the Educational Open Meeting are planned for the morning, while the afternoon will have an important open meeting to deal with the AWS activities of the Publicity and Promotion group. Tuesday evening will feature the Ohio State University Alumni Dinner. On Wednesday the Section Officers Meeting will be held and on Thursday the Board of Directors will have a regular business meeting. There will be a meeting to be announced later of the Missile and Rockets Welded Fabrication Committee. Further details will be published in September.

An Important Reminder

AUTHORS . . .

August 15th is the deadline when application forms and abstracts must be postmarked in order for papers to receive consideration for presentation at the 42nd Annual Meeting to be held in New York, Apr. 17–21, 1961.

The application form was included as a detachable insert in the May issue of the WELDING JOURNAL. Additional copies of the application, as well as "Instructions and Suggestions for Authors," may be obtained by writing to AWS headquarters, 33 W. 39th St., New York 18, N. Y.

Rapid Rise of UEC Building Acclaimed

United Engineering Center, the new home of AWS and other engineering societies, has been growing rapidly. This fact was noted by 18 national officers of AWS when they paid a quick visit to the construction site following a regular meeting of the Board of Directors on June 2nd. The short inspection tour, arranged by Secretary Plummer, revealed the excellent progress made to date. The steel erection started in early May and had advanced to the seventh floor at the time. Considering the heavier work involved in the lower stories, the steelwork is nearly half completed. Topping out is expected sometime in August. Present plans call for completion during the summer of 1961.

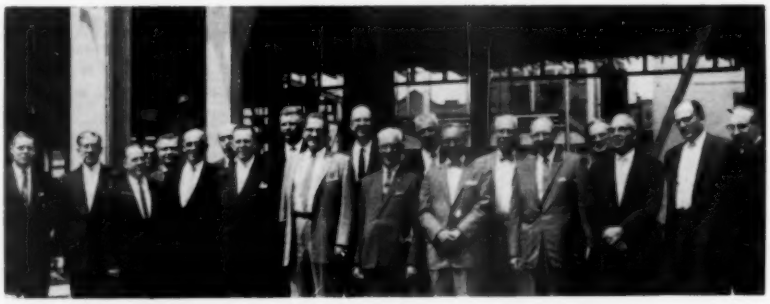
Cornerstone Set During Impressive Ceremony

On June 16th the cornerstone was laid at a ceremony during which former President Herbert Hoover and New York's Mayor Robert Wagner acclaimed the event. Mayor Wagner cited the rise of the engineering profession as a significant growth in modern society. He expressed the pride of the City of New York in having the UEC located here and emphasized the many advantages to be gained by this location.

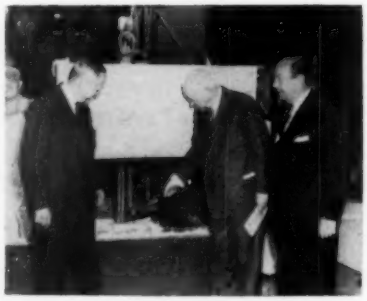
The dedication ceremony was further enlightened by Herbert Hoover who pointed out how engineers working in a free society could build a better world.

Andrew Fletcher, president of United Engineering Trustees, presided over the event.

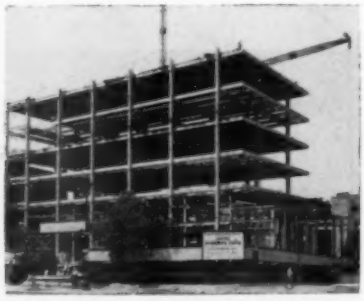
When completed, the 20-story structure will be faced with stainless steel, limestone and glass and will contain the most modern equipment. In addition to an extensive library, there will be meeting rooms, an exhibit hall, a large cafeteria, air conditioning and modern elevators. The entrance lobby opens on 47th St., facing the Carnegie Endowment for International Peace and looks obliquely across United Nations Plaza to the UN building. A temporary sign placed at the corner proclaims the UEC purpose, "To Advance America's Engineering Leadership."



Eighteen national officers toured the UEC construction site with Secretary Fred Plummer following the regular meeting of the Board of Directors on June 2, 1960. The group is standing at the future entrance



Herbert Hoover prepares to trowel the mortar for setting the cornerstone of the United Engineering Center. Andrew Fletcher, left, president of United Engineering Trustees, and New York's Mayor Wagner assist



Rapid progress in the erection of the United Engineering Center has brought the framework to the 7th floor

Hobart, Hoefler Appointed AWS Directors

W. H. Hobart, Jr., was appointed a director-at-large to fill the unexpired term of C. E. Jackson who became vice president.

R. H. Hoefler was appointed director of District No. 6 replacing J. N. Alcock who resigned.

Mr. Hobart is assistant secretary-treasurer of Hobart Bros. Co., Troy, Ohio, vice-president of the Hobart Technical School, vice-president of Florida Minerals Co. and a past-chairman of the Dayton Section of AWS. He is a graduate of Yale University and the University of Pennsylvania.

Mr. Hoefler is chief welding engineer of Kaighin and Hughes, Inc., Toledo, Ohio. He was previously with Brush Beryllium Co. as metallurgical and chemical research engineer. An instructor in welding engineering at the University of Toledo, he is a graduate of Case Institute of Technology and of the University of Maryland. A past-chairman of the Toledo Section, he has served on the National Nominating Committee and he received a National Meritorious Certificate Award in April 1960. A member of the Ohio Piping Code Advisory committee, he is also active in the ASME.

W. H. Hobart, Jr.

R. H. Hoefler

AT GATLINBURG, TENNESSEE MEETING

A group at the Gatlinburg, Tenn., meeting of the AWS Committee on Piping and Tubing. Left to right: S. C. Elms, F. C. Braun, D. C. Brown, G. E. Linnert (vice chairman) and E. C. Miller (chairman)

UNITED ENGINEERING CENTER FUND DRIVE

The Top Thirty (June 1, 1960)

Section	Goal, %	Section	Goal, %
Oklahoma City	125	Northeast Tennessee	100
Mahoning Valley	113	Olean-Bradford	100
Hartford	102	Pascagoula	100
Kansas City	102	Rochester	100
Puget Sound	102	Sangamon Valley	100
Baton Rouge	101	Santa Clara Valley	100
Niagara Frontier	101	Syracuse	100
Providence	101	Toledo	100
St. Louis	101	Western Mass.	100
Bridgeport	100	Wichita	100
Colorado	100	Detroit	99
Dayton	100	Philadelphia	97
Holston Valley	100	New York	92
Louisville	100	Northern New York	86
North Central Ohio	100	Maryland	78

CONTRIBUTE NOW TO THE NEW HOME OF AWS

In consideration of the gifts of others I intend to give to

UNITED ENGINEERING CENTER BUILDING FUND

_____ Dollars $_____

Paid herewith $_____ Balance will be paid as follows

_____

Credit my gift to:

☐ AWS ☐ _____

Signed _____

Print Name _____

Address _____

KEEPING YOU POSTED

by Fred L. Plummer

● Two-thirty A.M. on Friday, June 17th and your secretary stands at the window of his fourth-story room in the Hotel de la Couronne looking across the deserted street at the Station des Guillemins at Liège, Belgium. An industrious driver polishes the lone taxi hopefully waiting a late customer. A few hours ago your Secretary was guest with AWS President R. D. Thomas, Ship Structure Committee Chairman and Mrs. Edward Thiele (Rear Admiral and Engineer-in-Chief, U. S. Coast Guard), Guy Parsloe, Secretary of the British Institute of Welding and Secretary-General of the International Institute of Welding, at a dinner at which IIW President W. Edstrom of Sweden and his associate, A. Hanson, were hosts.

● This dinner at Le Chapon Fin followed an informal gathering of the 53 representatives (38 men and 15 ladies) of the United States at the 13th Annual Assembly of the International Institute of Welding in the beautiful new Palais des Congrès where the 15 working commissions with delegates and experts from 23 nations are holding four-day meetings dedicated to the assembly and interchange of information concerning the design and fabrication of welded assemblies.

● Officers of the Belgian Institute of Welding including President Frenay, IIW Founder President Goldschmidt-Clermont, M. Wauthier, M. Lambrecht, M. Liegéois, M. Soete and many others were responsible for organizing the Assembly, attended by some 700 representatives of the member countries. (See separate news release.)

● Last night the program included a reception, dinner and inspection of the welding exhibits at the "Foire Internationale de Liège." Members of the commissions include world famous scientists and engineers representing all major nations.

● The U. S. delegation, pictured in accompanying photographs, included, in addition to President Thomas, Admiral Thiele and your Secretary, the following: Aborn of U. S. Steel, Amirikian of Bureau of Yards and Docks, Andrew of Babcock and Wilcox, Ballas of General Dynamics, Begeman of Univ. of Texas, Boberg of Chicago Bridge and Iron, Claussen of Arcrods, Cohen of MIT, T. Crawford (Consulting Engineer), Crowley of Coast Guard, Felbeck of National Academy of Science, Frederick of G.E., Groth of Redstone Arsenal, Hogaboon of Bethlehem Steel, Hall of Univ. of Illinois, Hartbower of Watertown Arsenal, Hussey of Frankfort Arsenal, Jackson of Union Carbide, Jones of Precision Welder, Larson of Allis-Chalmers, Levinstein of G.E., McKenzie of Naval Weapons Plant, Miller of Union Carbide Nuclear, Mylonas of Brown Univ., Moore of Natl. Bureau of Standards, Offner of X-Ray Engineering International, Pulk of Ordnance Tank Automotive Command, Rieppel of Battelle Memorial Inst., Robertson of Coast Guard, Stout of Lehigh Univ., Trapp of Wright Air Development, Vasta of Bureau of Ships, Wasserman of Eutectic, Wheatley of A. O. Smith and Wundt of G.E..

● The 14th Assembly of IIW will be

Members of the U. S. delegation to the IIW Assembly in Liege, Belgium, June 13-19, 1960, gather at a reception held in the Palais des Congres. Rear Admiral Thiele took the picture

U. S. delegation at the 13th Annual Assembly of IIW attended reception in Salle des Fetes of the Palais des Congres as guests of Rear Admiral Thiele, AWS President Thomas and AWS Secretary Plummer

held in New York during April 1960, preceding and in conjunction with the Annual Meeting and Welding Exposition of AWS, the three events continuing from Apr. 10th to 21st, with IIW headquarters at the Sheraton-Atlantic Hotel, AWS headquarters at the Commodore Hotel and the Welding Exposition at the Coliseum.

● Representatives of IIW will participate in the AWS annual meeting following completion of the IIW assembly. Important contributions will include the Adams Lecture concerning "Cracking of and Transformation of Steels During Welding" to be given by M. H. Granjon of France; two lectures dealing with "Heat Sources, Heat Flow and Heat Effects" by N. N. Rykalin of Russia; a discussion of "Characteristics of Brazing Filler Metals and Fluxes" by C. G. Keel and G. M. A. Blanc of Switzerland, J. Colbus of West Germany and possibly another collaborator; "The Role of Hydrogen in Arc Welding with Coated Electrodes" to be presented by N. Christensen of Norway; an explanation of "Solutions Adopted in Some Difficult Applications of Flash Welding" by M. E. Bylin of Sweden; "Testing and Inspection of Welds on Plastics" to be summarized by G. A. Homes of Belgium; a report on "The Influence of Residual Stresses and Metallurgical Changes in Low-stress Brittle Fractures" by A. A. Wells of United Kingdom; a look at "The Future of the Design and Construction of Pressure Vessels" by W. B. Carlson of United Kingdom; a study of "The Use of Gas Mixtures in Shielded-Arc Welding" to be reported by M. M. Komers and L. Wolff of West Germany; description of "The Determination of the Fatigue Limit by Means of a Single Welded Specimen" by M. R. Cazand of France; discussion of "New Experimental Bases and Their Influence on the Calculation of Welded Assemblies" by A. Van Douwen of the Nethlerlands; and an excellent film showing use of electroslag welding in Russia with a lecture by B. E. Paton or some other outstanding Russian representative.

Part of the distinguished group of U. S. delegates at the Palais des Congres. From left to right: O. Frederick, General Electric Co., E. C. Miller, Union Carbide Nuclear Co.; W. E. McKenzie, U. S. Naval Weapons Plant; G. E. Claussen, Arcrods Co.; R. Stout, Lehigh University; W. S. Trapp, Wright Air Development Div. USAF; R. D. Thomas, Jr., Arcos Co.; I. E. Boberg, Chicago Bridge and Iron Co.

Rear Admiral E. H. Thiele, Engineer-in-chief, U. S. Coast Guard and chairman of the Ship Structure Committee, in conversation with AWS President R. D. Thomas, Jr., President of Arcos Corp.

A candid shot catches three delegates at a moment of leisure. Left to right: T. E. Jones, Precision Welder and Flexopress Corp.; J. B. Robertson, Coast Guard; T. Crawford, consultant

● On May 23rd President C. I. MacGuffie, EAC Chairman C. E. Jackson and your Secretary spoke at a dinner meeting of those attending the second educational course given in New York by the AWS School of Welding Technology under the direction of Education Secretary A. L. Phillips. This five-day course dealt with problems encountered in connection with the use of gas-shielded arc welding.

● President MacGuffie, President-elect Thomas and Treasurer Rockefeller spent May 26th with your Secretary and Assistant Treasurer Mooney preparing 1960–61 budget estimates, based on experience for 1959–60 and earlier years, and on projected plans for the next three years.

● Convention Manager Mooney and your Secretary visited Pittsburgh on May 27th to meet with Past-president G. O. Hoglund and chairmen of the local arrangement committees for the National Fall Meeting to be held there Sept. 26th–29th, 1960. Plans for this important meeting which will include addresses by President Thomas and AISI Vice-president Parker are well advanced. The Structural Division of ASCE and the Column Research Council will co-sponsor portions of the technical program.

● Returning to New York your Secretary was distressed to learn of the death in Tokyo on May 28th of R. D. Thomas, Sr., founder member of AWS, long time leader in the welding industry and in SOCIETY activities, who had recently been honored by election to Honorary Membership in the SOCIETY. R. D. Thomas, Jr., officially assumed the duties of AWS President on June 1st, a few days after the death of his father.

● Another severe loss came to AWS and the welding industry with the death in Cleveland on April 22nd of publisher and civic leader, Irving B. Hexter.

● On June 1st, first day of the new AWS fiscal year, your Executive and Finance Committee assembled at New York headquarters to prepare budget recommendations for presentation to your Board of Directors which met the following day in the Commodore Hotel to consider and approve the 1960–61 budget, appoint Secretary, Assistant Secretary and Assistant Treasurer, confirm recommendations of President Thomas covering officers and members of standing and special committees, authorize the formation of the "Orange County (Calif.)

JOIN AWS...

. . . and help build yourself a better future through a stronger and more prosperous welding industry. Grow with the industry and progress with AWS.

Your membership brings you these advantages:

- Welding Journal—The World's outstanding welding engineering and application magazine comes to you each month.
- Welding Handbook—The "Bible" of the welding industry—Full Members receive a new 500 page section each year.
- Section Activities—Each month you join other Section Members in meetings, plant tours, educational courses, social and recreational activities: greeting the experts, interchanging ideas, learning new welding know-how, enjoying fellowship and having good fun.
- National Activities—Annual Meetings, the Welding Exposition, more than one hundred technical and operating committees provide opportunities for your national participation.
- Welding Standards—You can help develop the manuals, codes and specifications used nationally and internationally to control welding and welded fabrication.

Why not join AWS now? For application form and additional details, write:

AMERICAN WELDING SOCIETY, INC.

33 WEST 39th STREET • NEW YORK 18, N. Y.

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DATE.....

NAME..... LAST FIRST MIDDLE

RESIDENCE ADDRESS

..... STREET

..... CITY ZONE STATE

COMPANY NAME.....

COMPANY ADDRESS..... STREET

..... CITY ZONE STATE

Title of position held.....

Mail should be sent to my residence ☐ company ☐ (check one)

I wish to be affiliated with the..... AWS Section

NOTE: To assure that your copy of the Welding Journal is mailed to your new address, this change of address notice must be received at American Welding Society, 33 West 39th Street, New York 18, N.Y., no later than the 25th of the month previous to issue mailing.

Section" of AWS and discuss and act on other questions involved in SOCIETY activities and plans for the coming year.

Following the meeting on June 2nd, officers and members of Board of Directors visited the site of the new United Engineering Center adjacent to the plaza of the United Nations Building. Here they were photographed viewing the construction of the welded steel frame (then at the 7th floor level) of this 20-story tower where your headquarters will be established during June 1961.

● On June 4th your Secretary flew by Pan American jet plane to London where he spent successive days with British Institute of Welding President E. Seymour-Semper (including a pleasant cruise on the Thames and delightful meals with both Mr. and Mrs. Seymour-Semper), with British Welding Research Association Director R. Weck and associates at the laboratories near Cambridge, and with International Institute of Welding Secretary General G. Parsloe (also Secretary of BIW), Asst. Sec. Boyd and other staff members at London headquarters of the British Institute of Welding.

● Your Secretary continued on June 9th to Liège, Belgium, for conferences with members of the Organizing Committee and the staff people who were responsible for planning and conducting the 13th Annual Assembly of the International Institute of Welding.

● Preassembly activities included an inspection of the welding exhibits of major European manufacturers at the "Liège Fair" which was open June 2–16th and an entertaining evening in Brussels with Jean-Jacques Cito and his charming wife.

● President Thomas joined your Secretary on June 12th for the full week of commission meetings, colloquia, special lectures and social activities. Official USA representatives at the June 12th and 18th meetings of the Governing Council were Admiral Thiele, President Thomas and your Secretary who was elected and assumed his duties as Vice President of IIW at the June 18th meeting and then attended the meeting of the Executive Council.

● These notes were begun during the early morning hours of June 17th. They are being finished on a Sabena jet plane flying from Brussels to New York on June 19th, following a farewell dinner with President Thomas and the David Boags of England at the beautiful Brussels home of C. Cito

EDUCATIONAL ACTIVITIES

Welding and Its Future

By JAMES M. SHILSTONE

Is the welding profession at this time completely meeting the needs of our space and nuclear activities? Are we capable of maintaining the United States at least equal to others in fields requiring high-quality welding performed efficiently at minimum cost? What are the prospects for these capabilities in future years?

According to Professor Roy B. McCauley, Chairman of Welding Engineering at Ohio State University, there will be only eight young men graduating in June of 1960 with a Bachelor of Science degree in Welding Engineering. Had we many universities offering this degree, this would not be too alarming. At this time, however, Ohio State University is the only university offering this degree. There are five such universities in Russia and three in Japan. It is frequently said that Russian universities are graduating more technical students than our American universities. This is certainly so in the welding engineering profession.

It is often stated at local meetings of the AWS that the local university should teach welding engineering or have subjects advancing the welding profession. Unfortunately, it is a case of supply and demand. Until there is a demand for such courses it is unreasonable to expect universities to devote time from their crowded schedules. This subject of welding courses has been discussed with members of the Engineering Department at Louisiana State University. Their reaction, and I am certain the reaction of practically all universities, is that there must be sufficient interest to warrant courses being provided.

From a practical point of view, in order to maintain an even keel in technical advancement in the United States, we must produce more technical people than does Russia. The reasoning is obvious. We work a 40 hour week and there is some talk of an even shorter work week. This means that we are losing ground daily to a nation which works longer hours with more technically trained people. If we worked 8 hours and the Russians worked 10 hours, they would gain 25%, everything else being equal. In order to offset this and maintain our way of life, we should produce at least 25% more graduates than they. In 1959 Russia was credited with graduating 850 welding engineers—in 1960 the U. S. graduated eight!

There is one solution to this problem. We must interest high school students in welding engineering as a profession. This is much easier to state than to fulfill. Too many people regard welding as the burning of an electrode, or the melting of a metal in a flame. This must be changed if we are to attract youngsters to take up welding. We know the tremendous challenge we are facing, the new processes under development and the new techniques made necessary by the new metals and alloys. It is our duty to let these facts be known; to make the high school boys aware of the fascinating world of metals, metallurgy and metal joining. Let us show them that there is much more to welding engineering than the burning of an electrode. Many have tried to present the welding engineering field at Career Day for high schools. Very few have been successful in such a presentation. Time is limited at these presentations and there are many fields other than welding to interest the students. We should not give up on these presentations, however. Each AMERICAN WELDING SOCIETY Section should approach the school boards and ask to be heard.

In Baton Rouge we have had some degree of success in a high school contest on subjects pertaining to the joining of metals. It has been well received by the School Board and we have obtained their complete support. Copies of correspondence by Dr. Lloyd Funchess, Superintendent of Schools, are available to be presented to other superintendents. Dr. Funchess has said repeatedly that one of the greatest needs in the American school system today on the high school level is for industry to give their support and to show the high school student the needs of the communities. These needs must be projected over a period of ten, fifteen or more years.

Last January, Section Secretaries and Chairmen received copies of a recommended procedure for the establishment of a high school science contest on subjects pertaining to the joining of metals. Additional copies may be obtained by writing to J. M. Shilstone, P.O. Box 123, Baton Rouge, La.

The High School Science Achievement Committee requests your assistance. We invite your comments and suggestions.

JAMES M. SHILSTONE is associated with Shilstone Testing Laboratory, Baton Rouge, La., and is chairman of the High School Science Achievement Committee of E.A.C.

AWS EDUCATIONAL COMMITTEE AT NEWARK PLANT

Members of the AWS Educational Committee who met at the Linde Laboratories, Newark, N. J., in May, discussed plans for the coming year. Left to right, rear: I. G. Betz, T. E. Jones, J. Light, M. Thomas, W. J. Williams, H. B. Cary, I. Goodman. Center row: O. T. Barnett, E. E. Goehringer, H. K. Hogan, E. C. Miller, chairman-elect. Front row: A. L. Phillips, secretary; R. B. McCauley, C. E. Jackson, chairman, and H. A. Sosnin

SECTION NEWS AND EVENTS

As reported to Catherine M. O'Leary

California

RESISTANCE-WELDING CONTROLS

Los Angeles—The scheduled speaker for the May 19th meeting of the *Los Angeles* Section, Budd L. Mack, sales manager, Electronic Controls for the Budd Co., Philadelphia, Pa., was unable to be present. However, he made arrangements with Bill Grant, West Coast representative for the Budd Co., to present his subject matter on "Monautronic V-2 and Monautronic V-3 Resistance Welding Controls." Mr. Grant did a remarkable job in substituting for Mr. Mack. The paper, with the support of slides, was well presented, with all the technical phases being well covered. Approximately 50 members and guests were present. The paper was preceded by a film in color shown through the courtesy of the District Steel Co., Los Angeles, entitled "The Snows of Tulupaca," a water diversion installation in the Peruvian Mountains using reinforced concrete lock-joint pipe manufactured on the spot, a joint venture of the Lock Joint Pipe Co. of New Jersey and the American Pipe and Construction Co. of Los Angeles.

RESISTANCE-WELDING CONTROLS

San Diego—A dinner meeting of the *San Diego* Section was held at the Streamliner Restaurant on May 18th with 57 members and guests present.

The meeting was opened by the newly elected Chairman J. R. Fullerton who presented a past-chairman pin to Robert Hawkins.

Technical speaker was Bill Grant, West Coast representative for the Budd Co. Mr Grant showed films and gave a talk on "Monautronic Controls for Resistance-welding Equipment."

ELECTRODES

San Diego—Seventy-five members and guests of the *San Diego* Section met at the Midway Chuck Wagon Restaurant on April 28th.

The following newly elected officers were introduced: J. R. Fullerton, chairman; R. D. Beemer, 1st vice chairman; W. J. Kairot, 2nd vice chairman; R. C. Manary, program chairman; L. E. Gary, membership chairman; D. E. Hughes, recording secretary; W. Graham, treasurer.

Technical speaker was William Arter, welding engineer for the A. O. Smith Corp. Mr. Arter presented some interesting slides and a talk on covered mild-steel and low-alloy electrodes.

Also present at the meeting was President Charles I. MacGuffie, who gave a brief talk on society activities.

INDUSTRIAL SAFETY

Oakland—On Monday evening, May 23rd, the *San Francisco* Section met for dinner and regular meeting at the Villa De La Paix in Oakland.

The main speaker of the evening was E. A. Brubaker, supervising engineer, Industrial Section, Division of Industrial Safety, Department of Industrial Relations, State of California. He spoke on the organization and functions of the Division of Industrial Safety as applied to welding operations. He gave some case histories involving the unsafe use of gas and electric-welding equipment as well as related hazards. He also presented some points to be used in a corrective educational program.

The election of officers for the coming year was held during the meeting.

As an added attraction Ted Connolly, a member of the San Fran-

ATTENTION SECTION SECRETARIES:

Notices for November 1960 meetings must reach JOURNAL office prior to August 20th so that they may be published in the October Section Meeting Calendar. Please give full information concerning time, place, topic and speaker for each meeting.

SAFETY DISCUSSED AT SAN FRANCISCO MEETING

E. A. Brubaker spoke on industrial safety precautions at the May 23rd meeting of San Francisco Section. He is shown standing above, fourth from left, with the members of the Executive Committee

A partial view of the members and guests in attendance at the meeting

cisco '49er professional football team, presented movies with comments on the highlights of the 1959 season. Besides playing football, Mr. Connolly is interested in welding through his connection with a local welding equipment company.

Officers elected by the Section for 1960–61 were announced as follows: Chairman, B. P. Faas, Standard Oil Co. of California; First Vice Chairman, W. L. Doherty, The Lincoln Electric Co., Second Vice Chairman, T. H. Hazlett, University of California; Treasurer, K. C. Cummings, Yuba Manufacturing Co.; Secretary, Lee Tinnes, Mare Island Naval Shipyard.

PLANT TOUR

Sunnyvale—Lockheed personnel acted as guides for 85 members of the *Santa Clara Valley* Section on Tuesday evening, May 31st, when they made a tour of the plant.

A good deal of interest was shown by the members in the inert-gas tungsten-arc welding of aluminum and magnesium that is being performed at Lockheed Missiles & Space Division plant in Sunnyvale.

The members were also afforded an opportunity to view various other types of operations being carried on in conjunction with the manufacturing of the Polaris missile. Of special interest to the welding-minded visitors was the manufacturing development laboratory. The new equipment being installed for automatic welding of aluminum and magnesium materials was quite impressive. The visiting members were quite appreciative and praised the fine housekeeping throughout the plants.

Connecticut

MAGNETIC-FLUX WELDING

Bridgeport—The *Bridgeport* Section met on May 31st at the Fairway Restaurant. Speaker was Robert T. Telford of the Linde Co., Newark, N. J.

Mr. Telford opened his talk with comments on slides pertaining to the principles of gas-shielded magnetic-flux welding. Cost data were given relative to other welding methods. Although material costs are higher for the magnetic-flux method, other savings result in an over-all cost reduction of about one-half, the speaker explained. The particular welding applications for which this process is best used were illustrated by a film.

DINNER DANCE

New London—On May 20th the *Hartford* Section held its annual dinner-dance and installation of officers at the Lighthouse Inn in New London.

This outstanding event which attracted more than 80 members and their ladies, was preceded by a cocktail party sponsored by the area vendors. Lobster and roast-beef dinners were served. Following dinner, a very brief business session was held during which the outgoing chairman, Bill Duncklee, reviewed the activities of the past season. As a token of appreciation for his work in bringing the New England Conference and Show to the high-level success that it was, a wrist watch was presented to District No. 1 Director George Kirkley. Mr. Duncklee presented incoming Section Chairman Harry McGlew with a gavel suitably engraved, symbolic of his taking over as chairman of the section for the coming season. In turn, Mr. McGlew introduced his officers for the coming year, as follows: Frank Wallace, 1st vice chairman; Vic Zdon, 2nd vice chairman; Leo Driscoll, secretary; and Rae Sopher, treasurer.

At the conclusion of the business meeting, dancing was enjoyed to music provided by Carl Olsen and his Harmonaires.

Illinois

EDUCATIONAL LECTURES

Chicago—The Educational Activities Committees of the *Chicago* Section is currently planning the Third Annual Educational Lecture Series for this Fall. The series will again be held in the Chicago Bridge & Iron Co.'s "Dome" meeting hall at 1305 W. 105th St., Chicago, Ill. The time will be 7:00 to 9:00 P.M., Thursday evenings. The subject "Welding Processes" will be presented as follows:

September 22nd—Metal-Arc Inert-Gas
September 29th—Tungsten-Arc Inert-Gas
October 6th—Resistance

DINNER DANCE HELD BY HARTFORD SECTION

A small section of the many members, guests and their ladies who attended the Dinner Dance held by Hartford Section on May 20th

Outgoing Section Chairman Bill Duncklee, left, is congratulated by Chairman-elect Harry McGlew after receiving past-chairman's pin

Director George Kirkley, left, thanks Mr. Duncklee after getting a watch for his contribution to New England Welding Conference and Show held in October 1959

WORCESTER SECTION HOLDS LADIES' NIGHT

A large number of members, guests and their wives attend the annual Ladies' Night held by the Worcester Section on May 26th

October 13th—Shielded Manual-Arc (Part I)
October 20th—Shielded Manual-Arc (Part II)

ANNUAL STAG

Peoria—The *Peoria* Section held its annual stag at John Hanley's cottage on the beautiful Illinois River. A buffet lunch was served at 6:30 P.M. to 75 hungry men. The food was thoroughly enjoyed.

This affair held on May 18th was the last meeting of the fiscal year.

Indiana

BUSINESS-SOCIAL

South Bend—The *Michiana* Section finished its 15th year of existence with the annual business-social meeting held on May 19th at Russ Restaurant.

Officers for the new year were the main piece of business. The following were elected: Chairman, Robert Bauss, Michiana Welding Supply Co.; Vice Chairman, Floyd Doolittle, Bendix Products Division; Treasurer, Leo Cuthbert, Whirlpool Corp.; Secretary, Gerard Fassnacht, Bendix Products Division; Executive Committee, Kenneth MacLaren, Samuel Hearrell, John Vaselin, Robert Schrader, Virgil Young and Woodrow Koehler.

Following the business meeting, three films were shown. One concerned the Talos surface-to-air missile, provided by the Mishawaka Div., Bendix Corp. Another told about background and highlights of a 500 mile race at Indianapolis. This was provided by the Champion Spark Plug Co. Finally, the story of the Mackinac Straits Bridge was shown through the courtesy of the U. S. Steel Corp.

Iowa

ANNUAL STAG

Des Moines—The *Iowa* Section held its annual stag dinner at the Garden Room of the Hotel Kirkwood on May 19th. It was attended and enjoyed by 39 members and guests.

The stag was preceded by a wonderful buffet dinner and a short business meeting.

Massachusetts

LADIES' NIGHT

Shrewsbury—Sixty-seven members and guests thoroughly enjoyed the annual *Worcester* Section Ladies' Night held this year on May 26th at the Svea Gille in Shrewsbury. An excellent Smorgasbord in traditional Swedish style was served. Dancing followed the dinner, and once more the Worcester Section ended a very successful year.

New York

INERT-GAS WELDING

Buffalo—The last meeting of the season for the *Niagara Frontier* Section was held at the Cypress on May 26th. Five past-chairmen were present to welcome Chairman John Kaluzny to their ranks and to install newly elected Chairman William Burch.

The speaker, Tom McElrath, of the Linde Co., reviewed new developments in inert-gas welding for the audience of 65. He showed how "short-arc" welding makes practical use of consumable-electrode welding on gages below $^{1}/_{16}$ in. This requires a gun which feeds 0.030 wire and a special high-reactance power supply. There are several brands of this equipment. Movies of the arc showed a drop transfer of metal, with the arc being extinguished about 100 times per second. The process is used on aluminum as well as on steel.

LADIES' NIGHT

Pittsfield—The annual meeting of the *Northern New York* Section, which consisted of a dinner-dance affair, was held at the Stanley Club in Pittsfield, Mass., on June 3rd.

ELECTION OF OFFICERS

Rochester—The last regular meeting of the *Rochester* Section for the 1959-60 season was held on May 16th at the Lyons Den. This meeting was for the annual election of officers. A smorgasbord supper was held followed by the business meeting and a bowling party. Well over 100 members and guests attended the meeting.

The newly elected officers and executive committee are as follows: Chairman, S. Evarts, Corning Glass Works; Vice Chairman, V. Cimino, Stromberg-Carlson; Treasuer, R. Cattanach, American Laundry Machine; Secretary, B. S. Payne, Pfaudler Co.; Executive Committee, H. Taylor, C. Meadows, L. R.Haslip, D. Evans, A. Chippero, R. Clelland, F. Spotts, S. Phillips and W. Allen.

The section has concluded a successful year and is looking forward to continued achievements in the future.

TALKS ON WELDED STRUCTURES

LaMotte Grover, right, spoke on "Design and Procedures for Welded Structures" at the May Meeting of the Carolina Section held in Greensboro, N. C. Shown with Mr. Grover are Chairman-elect Herb Owen, center, and Vice-chairman-elect Jim Martin, left

LADIES ENTERTAINED BY MAHONING VALLEY SECTION

These two scenes are typical of the festive atmosphere that reigned at the May 20th Ladies' Night affair sponsored by the Mahoning Valley Section

Ohio

LADIES' NIGHT

Columbus—A record turn-out of over 50 couples attended the annual "Ladies' Night" meeting of the *Columbus* Section held at The Desert Inn on May 28th. This meeting at the close of the year's activities has steadily increased in popularity. A dinner, followed by dancing, was thoroughly enjoyed by those attending.

Newly elected officers of the Section were introduced and Roy B. McCauley and Perry J. Rieppel, both recent recipients of AWS awards, were acknowledged during a brief after-dinner program. Dancing was interrupted occasionally to announce door-prize winners, providing additional entertainment for a very pleasant evening.

LADIES' NIGHT

Youngstown—The *Mahoning Valley* Section's Sixth Annual Ladies' Night was a memorable evening for 144 members, guests and their ladies.

A cocktail party initiated the night's events at the Victoria Restaurant on Friday, May 20th. A delicious dinner of lobster or steak followed.

After dinner, Chairman Emmet Craig introduced the new members of the Executive Committee and the newly elected officers, who are as follows: Robert H. Foxall, chairman; Jack Glass, first vice chairman; Edward Phelps, 2nd vice chairman and program chairman; Mike Bushwack, secretary-treasurer. The remaining members of the executive committee are: Emmet Craig, Fritz Forsthoefel, Jack Huna, Thomas Junk, Mel Oakley, R. D. Switzer and Kirke Taylor. Past-chairmen certificates were presented by Secretary Bob Foxall to Jack Manternach, Fritz Forsthoefel, Forrest Johnson and Emmet Craig.

To complete the evening, each lady present was given a gift. A "barbershop" choral group and a dance band provided the entertainment for the evening.

PLANT TOUR

New Philadelphia—Wednesday, April 13th, was the date of a memorable tour by members of the *Stark Central* Section of the plant of the Joy Mfg. Co. of New Philadelphia, Ohio.

Preceding the plant tour a social hour and dinner meeting was held at the Reeves Hotel where Mr.

PHILADELPHIA SECTION CELEBRATES WITH DINNER DANCE

Outgoing Chairman Frank Iapalucci, left, presents the emblematic gavel to his successor, Walter Wooding, at May 21st Dinner Dance held by Philadelphia Section

Here, newly inducted Chairman Wooding reverses the tables as he presents Mr. Iapalucci with past-chairman's pin

National Secretary F. L. Plummer and President R. D. Thomas receive $100 check to the new UEC building presented by Mr. Iapalucci on behalf of Lake Erie Machinery Co.

SPRING SOCIAL SPONSORED BY NORTH TEXAS SECTION

These are some of the merrymakers at the Spring Social held by the North Texas Section on May 13th

Here Mrs. Bill Koenig accepts a door prize from Rip Key

Wade, plant manager of Joy's New Philadelphia plant, spoke a few words of welcome, and also brought the audience up to date on future plans of the local plant. Mr. Wade stressed the important place welding has played in the growth of the local plant.

Pennsylvania

ANNUAL DINNER DANCE

Philadelphia—On May 21st, the *Philadelphia* Section again held its Annual Dinner Dance at the Germantown Cricket Club. This year the affair had an added feature.

Immediately preceding the dinner a reception was given to R. D. Thomas, Jr., newly elected president of the SOCIETY. The Philadelphia Section is not only proud of the fact that Mr. Thomas hails from their section but also of the fact that he is a past chairman, and has served on numerous committees, as well as being one of the "builders" of the group, never missing an opportunity to further the works of the SOCIETY and the cause of welding.

All in attendance at the dinner dance agreed that the food was the finest and the entertainment the best. The affair was very capably handled by Bill Brooks and his committee.

Past-chairman Frank Iapalucci and his wife journeyed from Buffalo to attend. He presented the gavel to Walter Wooding, his successor. Mr. Iapalucci also presented President Thomas with a check for $100.00 for the United Engineering Building Fund, donated by the Lake Erie Machinery Co.

The Section was pleased to have, as its guest, National Secretary Fred Plummer.

Rhode Island

NICKEL ALLOYS

Providence—The *Providence* Section held its May dinner meeting at Johnson's Hummocks on Wednesday, May 18th.

The new slate of officers were announced as follows: Chairman, Avery Seaman; First Vice Chairman, Richard Fogarty; Second Vice Chairman, John Bianco; Secretary, George Blome; Treasurer, W. Alan Smith; Director-at-large, Alden W. Thompson.

The Section was privileged to have, as speaker, Kenneth M. Spicer of Technical Services, Huntington Alloy Products Division, Huntington, W. Va. Mr. Spicer gave an impressive talk on the "Welding of Stainless Steels and Nickel-bearing Alloys." He spoke on the fundamental uses of nickel and high-nickel alloys in welding.

Texas

SPRING SOCIAL

Dallas—On Friday, May 13th, the *North Texas* Section held its annual Spring Social. After a buffet-style dinner, the 35 couples that attended danced to the music of Gardner Hinkley and his orchestra.

During the evening, the officers for the coming year were introduced and several door prizes were awarded. Everyone present had a fine time.

WELDING INSPECTION

San Antonio—The *San Antonio* Section held its June 6th meeting at Capt. Jim's with 50 members attending.

Gus Dugger, manager of the Steel Department of Trinity Testing Laboratory was the program speaker. His subject was on "Welding In-

OFFICERS OF SAN ANTONIO SECTION

These are some of the new officers and directors present at June 6th meeting of San Antonio Section. Left to right, seated, are J. Bergeron, secretary; Fred Smith, chairman; W. B. Hamilton, past chairman; B. F. Bahlman, director. Left to right, standing, W. N. Deason, L. F. Schenk, George Martin, Charles Brownrigg, E. E. Wagner, treasurer, and William Bentley

AT FOX VALLEY SECTION'S DINNER DANCE

Pictured at Spring Dinner Dance held by Fox Valley Section on May 14th are, left to right, Jack True, director; Robert Hart, secretary; Max Kern, past chairman; Stanley Manowske, second vice chairman; Gordon Jacklin, first vice chairman; Gerard Rasmussen, director; John Teigen, chairman; Robert Gehrt, director; and Thomas Krizenesky, treasurer

spection in General." He presented a fine program, touching on codes, welder qualification, procedure qualification, X-ray and the reasons for inspection, in the first place. A series of color slides of test welds, test bends and others accompanied Mr. Dugger's talk.

Wisconsin

SPRING DINNER DANCE

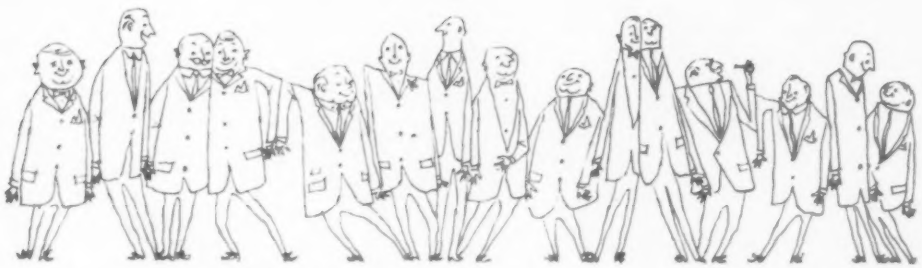
Appleton—The Annual Spring Dinner Dance of the *Fox Valley* Section was held on Saturday evening, May 14th at the Appleton, Wis., Elk's Club.

Six o'clock cocktails preceded a 7:00 o'clock chicken dinner.

A short meeting followed the dinner, at which time the new officers were introduced. Publicity Chairman J. G. Waldron acted as master of ceremonies.

The meeting was followed by dancing from 9:00 P.M. to 1:00 A.M.

There were flowers for the ladies and door prizes were given out on the hour during the course of the evening. One hundred and seventy-five people attended the event.



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■ Take approximately 50,000 readers vitally interested in the Welding Industry . . . in its research and constant development. Give them a magazine that keeps them up-to-the-minute about their industry . . . about the people who make news in welding . . . where they go, what they do, when they do it.

■ Such a group of men, closely welded together by a common interest, are the heart and fiber of the Welding Industry . . . and the Welding Journal is their medium of communication.

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if your production depends on welding... call in *LINCOLN*

(specialists in arc welding)

AKANSAS implement manufacturer increased his plant production over 30 percent when the Field Engineer from LINCOLN added a Twinarc attachment to his automatic welding installation. With the savings of the first couple of weeks, he bought another Twinarc and further cut costs.

Here's proof that some production problems can be solved without expensive capital equipment purchases. In this case, just a simple attachment did the job—and it was a standard item in the LINCOLN line.

But it takes a working knowledge of the overall production problem to engineer welding applications efficiently. And that's where the LINCOLN Field Engineer comes in. Sure he sells welding—but more than that, he brings manufacturing know-how into your plant and solves his assigned problem without creating a dozen new ones. He's not only an engineer, he's a weldor. He rolls up his sleeves and demonstrates his recommendations. And, as he engineers the application, he relates it carefully to the overall production operation.

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LINCOLN WELDERS

For details, circle No. 8 on Reader Information Card

New Members

EFFECTIVE JUNE 1, 1960

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	202
Members	6,445
Associate Members	5,813
Students	286
Honorary Members	11
Life Members	28
Total	12,785

AWS Builds Men of Welding

BOSTON
Keating, William R. (B)
Markey, Richard F. (B)
Travis, Roger E. (D)

BRIDGEPORT
Harco, Peter Paul (B)

CANADA
Burns, William J. (B)
Slaughter, James A. (B)

CAROLINA
Ferree, James S., Jr. (B)
McGraw, E. P. (C)

CHICAGO
Campbell, Paul R. (B)
Saboff, George (B)

CLEVELAND
Lee, William John (B)
Patnik, A. S. (C)
Tschappat, D. W. (C)

COLORADO
Barker, Robert B. (B)
Robinson, M. Keith (B)

COLUMBUS
D'Annessa, Antony T. (D)
Fix, Michael R. (D)
Freeman, Norman D. (D)

DAYTON
Hancock, Robert A. (B)
Prass, Jerry G. (D)

DETROIT
Alyea, H. B. (B)
Caponi, Chester S. (B)
Green, Al (B)
Houston, Carl W. (B)
Jones, Ward N. (B)
Saunders, Stanley R. (B)
Vetter, Roland H. (B)

EASTERN ILLINOIS
Pruitt, Earl Dean (C)
McDaniel, Glen E. (B)

HOLSTON VALLEY
Roberts, Edward R. (B)

HOUSTON
Heidrich, Everett R. (B)
Looper, B. N. (B)
Selle, J. B. (B)
Ware, Clinton L. (B)

INDIANA
Bowers, Gerald V. (C)
Brothers, Everett (B)
Fulkerson, Thomas Earl (C)
Fulleton, Leonard G. (B)
Imes, R. H. (B)
Neff, Otto Anthony (B)

KANSAS CITY
Claybaugh, Robert H. (B)

LEHIGH VALLEY
Decker, Erwin L. (B)
Pense, Alan W. (C)
Rathbone, Allan M. (C)

LONG BEACH
Britton, William S. (B)
Covington, Robert R. (B)

LONG ISLAND
Greagor, John W. (C)

LOS ANGELES
Arthur, W. L. (C)
Bustrum, Glenn A. (B)
Chapman, Gordon J. (C)
Cogorno, Albert (B)
Daniels, Stanley (B)
Jones, R. H. (C)
Labberton, Helios V. (D)
Poe, Walter (C)
Reese, Bill T. C. (B)
Teal, Edward J. (C)
Toomey, William H. (C)

MADISON
Barrett, James C. (C)
Boudreau, Don (B)
Brethorst, Wilfred E. (C)
Brinsmade, Harold S. (D)
Reisenauer, Orville (B)
Sheets, B. J. (B)

MAHONING VALLEY
Feldhouse, Harold E., Jr. (B)

MILWAUKEE
Bancroft, Richard M. (C)
Fiore, Edward J., Jr. (C)
Matters, Robert (B)
Schumbacker, Willerd (B)

MOBILE
Garris, Joe R. (C)

NASHVILLE
Swiggart, William H., III (B)

NEW JERSEY
DeHuff, John A. (B)

NEW ORLEANS
Tudury, Victor J. (B)

NEW YORK
Hays, Otho E. (D)
Hudecek, Frank J. (C)
Mitchell, E. P. (C)
Roe, Walter G. (B)
Tesmen, Arthur B. (B)

NORTH TEXAS
Daugherty, J. R. (C)
Holland, Henry E. (C)
Rosson, Jessie C. (C)
Zunk, Harold B. (C)

NORTHWESTERN PENNSYLVANIA
Kurtis, Edward (C)
Perry, Charles F. (B)

OKLAHOMA CITY
Stephens, Peter D. (C)

PASCAGOULA
Boardman, John Robeson (C)
Costello, Dan (B)
Hopkins, James S. (B)

PEORIA
Larson, F. W. (C)
Patterson, Wallace (C)
Syfert, James L. (C)

PHILADELPHIA
Edwards, Thomas V. (B)
Kelly, Edward P. (C)
Kelly, Henry J. (B)
Magruder, Peter P. (C)
Marsden, George E. (D)
Walberg, George M. (B)
Roberts, Howard C. (C)

PITTSBURGH
Davis, John L. (C)
Rattigan, Arthur A. (C)

PROVIDENCE
Stikeman, Warren J. (B)

PUGET SOUND
Williams, Grant M. (C)

RICHMOND
Ramsey, Frank E., Jr. (C)

ST. LOUIS
Kogler, Frank (B)

SALT LAKE CITY
Kirk, William L. (C)

SAN DIEGO
Hall, George E. (B)

SAN FRANCISCO
Ballinger, Floyd E. (B)
Bunn, Joe A. (B)
Hanley, Robert J. (B)
Swanson, T. M. (B)

SANTA CLARA VALLEY
Domina, Fred H. (A)

STARK CENTRAL
Noble, George A. (B)

SUSQUEHANNA VALLEY
Lesek, William (C)

SYRACUSE
Tanner, Frank A. (B)

WESTERN MICHIGAN
Stevens, C. Leigh, II (B)

MEMBERS NOT IN SECTIONS
Lindsey, John (C)
Boyd, G. M. (B)
Verchere, Louis Jean (B)
Rao, K. K. (B)

Members Reclassified During June

CHICAGO
Franz, Raymond J. (C to B)

LOS ANGELES
Herzman, Robert R. (D to B)

NEW JERSEY
MacGuffie, C. I. (A to F)

NEW YORK
Plummer, Fred L. (F to E)

PHILADELPHIA
Thomas, R. D., Sr. (A to E)

SANGAMON VALLEY
Bruckner, Walter H. (C to B)

NEWS of the industry

Lincoln Appoints Managers

The Lincoln Electric Co. has announced the appointments of J. L. Munson as manager, administrative services, and of R. F. Young as credit manager.

Mr. Munson will coordinate various administrative service departments to improve the efficiency of office operations and communications.

Mr. Young was formerly assistant credit manager and at his new post succeeds Mr. Munson.

RWMA Cites High Shipments

For the fourth consecutive month, shipments of resistance welding equipment have been well over $2 million, according to the statistics compiled monthly by the Resistance Welder Manufacturers Association.

Figures on new business for the first five months of the year reflect an increase of 13% over 1959 business, while shipments are 28% ahead of the same period last year.

Backlogs remain high, with more than $11\frac{1}{2}$ million reported as of May 31st.

Training Course By All-State

All-State Welding Alloys Co., Inc., of White Plains, N. Y., offers free welding, brazing and soldering instruction programs and live demonstrations designed to fit the needs of individual industries, according to a recent announcement.

All-State's technical training program is divided into three parts. Three-day accelerated courses are offered for practical workmen. An intensive week long course is also offered for welding, brazing and soldering salesmen. The third phase of All-State's program is a flexible series of technical demonstrations and lectures given to acquaint welding, brazing and soldering users with the latest information for their particular industry.

Federal Machine and Welder Appoints Representative

Harrington-Wilson-Daum Corp., Mount Vernon, N. Y., announces that their firm has been appointed sales and service representatives for The Federal Machine and Welder line of "Federal" resistance welding machines. The newly appointed representatives cover the northern New Jersey, Metropolitan New York and Long Island area.

Haines Board Chairman; Dunham Is President

Charles J. Haines, president of Chemetron Corp. for 23 years, was elected chairman by the board of directors and James W. Dunham was elected president of the company following the recent annual stockholders meeting. Mr. Haines, an engineer from the University of Missouri, is one of the founders of the company. Mr. Dunham is a chemical engineer from MIT and has served the company in production, engineering, research and finance. He is a past-president of the Compressed Gas Assn. and of the International Acetylene Assn.

Witzleben Elected

Norman A. Witzleben has been elected secretary-treasurer and a director of National Electric Welding Machines Co., Edward C. Smith, president, announced recently.

Mr. Witzleben's election fills a vacancy on the board of directors created last August by the death of Charles E. Shearer, who had also served as secretary of the company. Witzleben, 44, joined National in 1936 as a timekeeper. He was named treasurer and assistant secretary in August 1958.

Harnischfeger Earnings Up

Six-month earnings for Harnischfeger Corp. are up 5% over the same period last year, according to an interim report to stockholders covering the period Nov. 1st through April 30th.

Net earnings were $857,266 against $815,904 for the same six months last year, or $1.09 per share as against $1.04 per share. Net sales for the Milwaukee firm increased $1,115,768. This represents an advance of about 3% from $38,302,108 to $39,417,876.

The report was released following a regular monthly meeting of the board of directors, at which the board also declared its normal quarterly dividend of 40¢ per share payable July 1st to holders of common shares of record June 20th.

COMING EVENTS

A Calendar of Welding Activity

AWS

1960 National Fall Meeting. September 26–29. Penn-Sheraton Hotel, Pittsburgh, Pa.

Oct. 13–15 Third Western Welding Show, Exposition Hall, Santa Clara County Fair Grounds, San Jose, Calif. Western Welding Technical Conference, St. Claire Hotel.

1961 Annual Meeting & Exposition: April 17–21. Hotel Commodore, New York, N. Y.

AEC

Oct. 4–6. Southwest Research Institute—Welding Forum, Hilton Hotel, San Antonio, Texas.

ASM

Oct. 17–21. 42nd National Metal Congress and Exposition. Convention Halls and Bellevue-Stratford Hotel, Philadelphia, Pa.

Radionics, Inc., Makes Debut

Radionics, Inc., of Norristown, Pa., was recently organized to operate in the field of industrial applications of nuclear radiation. The new company has for its nucleus Radiation Engineered Services of Norristown, Pa., producers of industrial gamma radiography sources and equipment.

The new company will continue to market the gamma radiography line, and, later this year, will introduce a complete line of isotope thickness-density gages and gamma probing equipment for flaw detection in very thick sections of heavy materials, according to recent reports.

Radiation Engineered Services, operated as a division of Radionics, was formerly owned by A. J. Stevens and L. P. Farrell. Mr. Stevens is president of the new concern, and Mr. Farrell is secretary-treasurer. Directors include P. K. Bloch, president of Branson Instruments, Inc., L. Uphoff, vice president of Branson, and T. Morgan, president of Charles T. Morgan Co. of Beverly, Mass.

Airco Adds Liquid Air Unit

A liquid air plant producing 120 tons of oxygen per day was added to the existing facilities of Airco's Butler, Pa., plant, it was announced recently. The oxygen is piped directly to the Butler Works of the Armco Steel Corp. where it is used

in steelmaking. Nitrogen is also used by the Butler Works. The nitrogen and argon simultaneously produced with the oxygen, together with the production from the previously existing facilities, is for sales distribution over an area with a 500 mile radius.

Shieldalloy Opens Warehouse

A sales office and warehouse has been established in Detroit by Shieldalloy Corp., producers of ferro alloys, master alloys and metals, processed minerals and ores. Located at 14360 Livernois Ave., the office will serve specialty steel producers, foundries and other users of metallurgical materials.

Walter H. Fischer, formerly at Shieldalloy headquarters in Newfield, N. J., has been put in charge of the new office.

Braucht Appointed Manager

Rankin Manufacturing Co. announces the appointment of T. C. Braucht as district manager of the southern district, covering Texas, Oklahoma, Arkansas, Louisiana and Alabama.

Mr. Braucht is a hard-surfacing specialist having had four years' experience as a field representative tor the Rankin Co. and four years as a distributor.

Represent United Specialties

United Specialties, Inc., El Dorado, Ark., manufacturers of hose and cable reels, have appointed the following representatives: Nicholson Products Co., Clifton, N. J.—northern New Jersey and part of southeastern New York; Craig Industrial Equipment Co., Memphis, Tenn.—western Tennessee and northern Mississippi; Industrial Engineering Sales Co., Chicago, Ill.—northern Illinois and Lake County, Indiana; W. J. Bernhart Co., Inc., Buffalo, N. Y.—western New York State.

ACRO WELDER MFG. CO.

MILWAUKEE

WELDING ENGINEERS

MACHINERY BUILDERS

ESTABLISHED 1936

ACRO® general purpose spot-projection-butt-seam resistance welding machines.

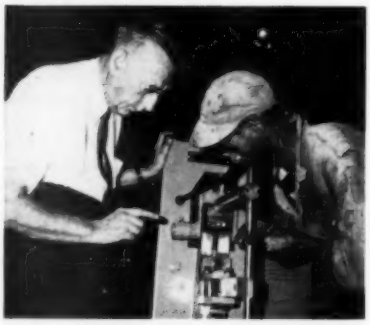
ACRO-ARC® special purpose production welding machinery employing automatic arc welding processes.

ACROMATIC® special purpose production welding machinery employing resistance welding processes.

ACRO-MAGNETIC® magnetic force spot, projection, and percussion welding machines.

For details, circle No. 9 on Reader Information Card

U.S. INSTRUCTOR AT CASABLANCA FAIR



At the U. S. Exhibit in the Casablanca International Trade Fair (April 28th–May 15th), P. M. Hall, former RWMA president, teaches spot-welding technique. Unit was part of a simple production line routine of stamping, forming and welding

Air Reduction Opens Training School

A new training school was opened at the Houston, Tex., office of Air Reduction Sales Co., for the purpose of training distributor personnel in the practical application and the theory of modern welding practices.

Classroom lecture at new Airco training school for distributors, Houston, Tex.

DISTRIBUTORS TRAINING COURSE

Typical session at one of the training courses held for distributors by Harris Calorific Co. at Cleveland, Ohio. Instructor demonstrates use of torch

BACK TO SCHOOL

Thirteen distributor representatives who attended the NCG school in Chicago and their instructors are as follows: First row—J. Whitney, E. Duckett, W. F. Weinke. Second row—N. D'Alessandro, D. Evans, Jr., N. C. Tlane, F. Finn, R. White. Third row—A. E. Dailey, Lee O'Donnell, F. Krawiec, G. Hergert, R. Von Dulm. Back row—S. Linck, T. Elseth, J. Howery, V. Rohr

World's Finest CUTTING and WELDING TIP CLEANERS

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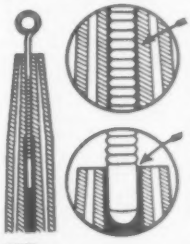
WIPES AND POLISHES

YOU GET SO MUCH MORE IN WYPO
Made of Stainless Steel

DOUBLES THE LIFE OF YOUR WELDING AND CUTTING TIPS

The exclusive circle design found only in Wypo Cutting and Welding Tip Cleaners provides as many as 60 more cleaning edges per inch of cleaner.



These rounded outer edges of cleaning ridges clean and polish tip orifice without scratching or cutting.

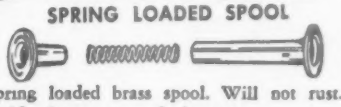
This smooth pilot guides WYPO Tip Cleaner into tip Will not enlarge or damage tip port.

This cross section view of WYPO Cleaning Surfaces shows these exclusive features:

Rounded cleaning surfaces that won't jam or cut.

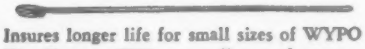
Straight sided valleys insure thoro cleaning by removing all waste.

SPRING LOADED SPOOL



Spring loaded brass spool. Will not rust. Holds cleaners securely in case.

DOUBLE WOUND EYES



Insures longer life for small sizes of WYPO Tip Cleaners. Will not pull out of case.

NOW AVAILABLE IN 3 CONVENIENT SETS

WYPO TIP CLEANERS
STANDARD SET

CLEANER NO.	FOR DRILL
7	75-74
8	73-72-71
10	70-69-68
12	67-66-65
14	64-63-62
15	61-60
16	59-58
17	57
18	56
22	55-54
24	53-52
26	51-50 49

MADE IN U.S.A.
PAT NOS 2629581, 2672758 IN CANADA 1968

STANDARD SET OF (12) Cleans (27) Drill Sizes Nos. 75 to 49 Incl.

WYPO TIP CLEANERS
JUMBO SET

CLEANER NO.	FOR DRILL
28	48-47
30	46-45
32	44-43
34	42-41
37	40-39-38
39	37-36
42	35-34-33
44	33-31
45	30

MADE IN U.S.A.
PAT NOS 2629581, 2672758 IN CANADA 1968

JUMBO SET OF (9) Cleans (19) Drill Sizes Nos. 48 to 30 Incl.

MASTER SET

CLEANER NO.	FOR DRILL
7	75-74
8	73-72-71
10	70-69-68
12	67-66-65
14	64-63-62
15	61-60
16	59-58
17	57
18	56
22	55-54
24	53-52
26	51-50-49
28	48-47
30	46-45
32	44-43
34	42-41
37	40-39-38
39	37-36
42	35-34-33
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Dear Mr. Rossi:

When you read in the paper that some communistic country or some country controlled by a dictator has confiscated people's property, you hear the expression—"Thank the Lord that I live in America—it can't happen here."

Confiscation of property is happening in the United States. Just like leprosy or cancer, it is slowly but surely destroying our resources and wealth. This confiscation of property is done by unfair, immoral and unconstitutional excessive misapplication of taxation.

My property is being confiscated by such taxation. Let me explain this in detail because it has a serious effect on your own futures and property.

A little over thirty years ago, I started a small company that came to be known as Miller Electric Manufacturing Co. I ran this business alone for several years. Then I decided to incorporate because there was more prestige and confidence in the corporate form of doing business.

As it is well known, we had little capital. We had, however, energy, good health, confidence and enthusiasm and each year we built a successfully larger corporation.

We paid no dividends because we used dividend money for working capital. Consequently, we did not have to borrow.

Our records will prove that we have paid the Federal and State Tax Bureaus about 59% of our profits as taxes year after year. There was taxation on property already taxed simply because we owned it.

Being a large majority stockholder, I believed I was building a business I could consider my own and that I was personally paying taxes on its income year after year.

I had to pay a high tax rate on earnings of the company I owned. The money held by the corporation as dividends was taxed. As soon as I received the dividends, they were again taxed. The combined total of tax rates on the dividends was greater than the dividends. In other words, this property was confiscated by the tax bureaus.

After several years of this type of alleged legal robbery of property, I made a heart breaking discovery. I could not let my family carry on my business because of the confiscatory inheritance taxes that would be involved. My family would not have enough money to pay the inheritance taxes. This meant my business would have to be liquidated to satisfy the selfish bureaucrats who have wasted billions of dollars of tax money.

Consequently, I started to go around to some of the best tax experts in the country to find a way to solve our problem. Their answer was always the same—"Well, Mr. Miller, you are so right. This is confiscation of your property by the government bureaus, but at the moment, it is considered legal."

I have been determined to set up some kind of liquid fund to help my heirs pay the inheritance taxes so that my business can continue. However, the confiscatory nature of the taxes involved prevents me from doing so.

I could sell this corporation and pay a capital gains tax, which would still leave me enough to be in a fairly good financial position. But this would not solve the problem. It would not contribute anything toward destroying this evil confiscation of property through unconstitutional taxation. We have worked too long and too hard to give in to the bureaucrats.

There is a possible solution that warrants consideration. This means fighting the bureaucrats in court in attempting to put an end to confiscation of property by taxation. I am willing to sacrifice my time and money and jeopardize the rest of my future. But I need your support and encouragement to the fullest extent. I hope you will give it to me.

One of the first and important things to do is to eliminate the double taxation on dividends, or at least consider dividends as something other than straight income. The least that could be done would be to permit the few stockholders in a closed corporation to receive dividends and treat them the same as capital gains for tax purposes because actually dividends are capital gains.

It is hard to believe that in the United States of America, confiscation of property by taxation was ever intended to occur by those senators and representatives who originated our tax laws. I honestly believe the present senators and representatives can and would be willing to clear up the situation of double taxation on closed corporations. However, it must be brought to their close attention.

I am writing this letter because I feel so strongly about maintaining the company I have built, and I know that many of my friends are in a similar situation. If we had a concerted action by injured people like myself, I am sure we can get the reputation of the United States of America back where it belongs.

I will appreciate your help, and if you concur with me and write to your congressman, I will appreciate a copy of your letter.

NIELS C. MILLER, President
Miller Electric
Manufacturing Co., Inc.

Who's who?

The Who's Who in Welding read* THE WELDING JOURNAL. *The Journal is required reading for more than 50,000 potential buyers . . . key men in their respective fields . . . representing the largest concentration of purchasing power in the metal-fabricating world.*

** These are the people who buy and influence buying of welded products.*

PERSONNEL

Talento Named Advertising Manager

Frederick J. Talento, Jr., who joined the staff of the WELDING JOURNAL in June 1959, has been named national advertising manager, it is announced by B. E. Rossi, editor.

Mr. Talento was formerly a member of the *Look* magazine sales staff where he served as manager of automotive market development. Prior to that he was with Batten, Barton, Durstine and Osborne as an account executive on the DeSoto account. He attended the University of Notre Dame. Mr. Talento's duties will make him responsible for all JOURNAL advertising.

McClure Appointed Chief

George M. McClure AWS has been appointed chief of applied mechanics research in Battelle Memorial Institute's department of mechanical engineering. He assumes the former post of Horace J. Grover who became staff physicist at the same time.

Mr. McClure will be responsible for the group of research scientists engaged in design stress analysis and in studies of fatigue and other properties affecting equipment design. He is a member of the ASME committee on brittle fracture, the papers committee of SESA and is affiliated with the ASA, AGA and API engineering societies.

Skeie Heads Inspection

Kermit A. Skeie AWS, formerly western region manager for the Magnaflux Corp., has been transferred to Chicago where he will be in charge of the company's plants handling commercial inspection in sixteen principal cities.

Mr. Skeie joined Magnaflux in 1945 as a research engineer and later became a field engineer and district manager in Chicago. He is active in a number of engineering societies and civic groups. He is succeeded on the West Coast by Richard Turner.

Other appointments include Denis P. Walsh who became manager of distributor sales; Robert G. Strother who is now in charge of field engineering; and Henry Bogart who succeeded Mr. Strother as New York branch manager.

Doyle Named Field Supervisor

Howard E. Doyle AWS has been named a field supervisor for Eutectic Welding Alloys Corp. He will operate from the Minneapolis Service and Training Center from where he will cover Minnesota, North and South Dakota and Northern Wisconsin.

Oleair Becomes Product Manager

Alex M. Oleair AWS was made product manager of the Nelson Stud Welding division of Gregory Industries, Inc. His special field will be steel mills and transportation industries.

Other appointments, announced at the same time, include R. C. Friedly as general sales manager, P. H. Butterfield as product manager for construction and G. T. Kramer, product manager for industrial sales.

Mr. Oleair joined Nelson in 1947 and returned to Lorain headquarters in 1959 after serving seven years as a field engineer and branch manager in the Philadelphia-Baltimore-Washington territory.

Julicher Joins Saxe

A. J. Julicher AWS became associated with Van Rensselaer P. Saxe on July 1, 1960. He will be handling the promotion of Saxe Clips for the Baltimore, Md., organization. Mr. Julicher was for-

A. M. Oleair

K. A. Skeie

F. J. Talento

G. M. McClure

H. E. Doyle

merly associated with the AISC, serving as district engineer out of Boston, Mass. His new address is 1701 St. Paul St., Baltimore, Md.

Madsen Promoted

Orla Madsen, formerly serving as electrical engineer of C. B. Herrick Mfg. Co., has been promoted to chief engineer of the company. Born in Denmark, Mr. Madsen has accumulated a variety of experience in Canada and other countries. In his new capacity he will have charge of both electrical and mechanical operations.

Smith, Camargo Appointed

The appointment of D. S. Smith as publicity manager has been announced by All-State Welding Alloys Co., Inc., of White Plains, N. Y.

Prior to joining All-State, Mr. Smith was an editor for the *Engineering & Mining Journal*, a McGraw-Hill publication. He is a graduate of Columbia University and attended the Colorado School of Mines.

The appointment of M. Camargo, Jr., as assistant export manager was also announced. Mr. Camargo has 17 years' experience in the export field. His duties include foreign sales promotion as well as supervision of all phases of the export department and relations with All-State's overseas salesmen, affiliates and customers.

Thorne, Bach Promoted

National Electric Welding Machines Co., Bay City, Mich., has announced two promotions.

Paul Thorne AWS, formerly chief electrical engineer, has been named chief electrical and development engineer. His new duties involve development of electronic applications in the building of automated welding machines. He will also be in charge of the laboratory and samples section.

Harold Bach AWS, 20-yr veteran with the company and former manager of the service and research section, has been named chief welding engineer. Mr. Bach will remain in charge of service and test and has been made consultant liaison between engineering and test.

Lunati Retires

Twenty-eight years' service with National Cylinder Gas Division of Chemetron Corp. was celebrated recently at a retirement dinner for J. P. Lunati, superintendent of the NCG acetylene-producing plant in Memphis. Sam P. Ryland, NCG district manager, spoke at the dinner, and an engraved pen and a gold watch chain were presented by fellow employees.

Solarz Made District Manager

Appointed manager of the northeastern district of Rankin Manufacturing Co., William Solarz will be headquartered at Cleveland. He will be available for consultation on direct field assistance to customers in Eastern Canada, New England, New York, Michigan and Ohio.

Allen Joins Thermex

Ted Allen, formerly with The Budd Co., Gary, Ind., has joined Thermex Metallurgical, Inc., as a sales engineer for thermit welding. Operating from Hammond, Ind., he will serve accounts in Chicago and surrounding industrial areas.

Smith Made Sales Director

Warren Smith AWS has been appointed assistant director of manufacturing sales for welding fittings and flanges of Midwest Piping Co., Inc., St. Louis. He will work with field representatives to implement distributor sales. His headquarters will be at Midwest's home office in St. Louis.

Mr. Smith has been associated with Midwest for 8 years, as sales representative in New York, and more recently as sales manager, Pacific Division, with offices in Los Angeles. He is a former marine engineer, and was chairman of the Southern California section of the Society of Naval Architects and Marine Engineers.

Miller Made Superintendent

George J. Miller has been appointed plant superintendent at Newark, Calif., for Titan Metal Manufacturing Co., Division of Cerro de Pasco Corp. At the local plant, Titan produces a complete line of bronze welding rod, for the 13-states West.

In his new post, Mr. Miller has over-all responsibility for the production, shipping and maintenance departments.

A native of New York State, Mr. Miller won his B.S. in metallurgy in

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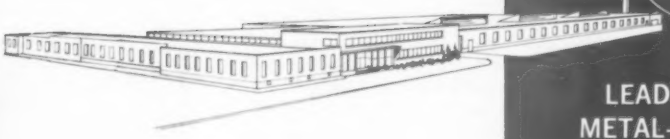

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Recognized for continued growth, as probably the most successful organization in the welding industry over the past 10 years, we offer qualified persons the opportunity to distinguish themselves, to be accepted on their merits and obtain rapid advancement.

Our laboratories in New York, and those recently constructed at St. Sulpice, near Lausanne, Switzerland have available the latest models of modern research equipment.

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J. F. QUAAS

We offer interesting opportunities in the following departments:

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7. Development of refractory metals and stainless metals with resistance to high temperatures.

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My associates and I would be pleased to meet you, and your interview would be in the strictest confidence.

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EUTECTIC WELDING ALLOYS CORP.
40-40 172nd Street, Flushing 58, New York

Mr. Rene D. Wasserman, President
Eutectic Welding Alloys Corporation
40-40 172nd Street, Flushing 58, New York
Mark your envelope "Personal"

1950 at Pennsylvania State University. Soon after graduation, he joined Titan's Bellefonte, Pa., headquarters as a metallurgist. He became a research metallurgist in 1954.

Petty, Davies Appointed Sales Representatives

Gulf Coast and Cleveland area sales representatives for its welding and portable lighting and power distribution equipment and systems have been appointed by J. B. Nottingham & Co., Inc., 441 Lexington Ave., New York 17, N.Y.

Charles Petty, Jr., 4025 Sierra Dr., Mobile, Ala., will represent the company in the Gulf Coast area, from Mobile through Houston, Tex. He has been an executive of The Ingalls Shipbuilding Corp. in Pascagoula, Miss.

Floyd Davies, 14712 Leonard Ave., Cleveland 7, Ohio, will represent the company in that city and surrounding industrial area. A former executive of Erico Products, Inc., he has had extensive experience in electrical and welding fields.

Clark Eastern Manager

The appointment of William C. Clark, Jr., as eastern regional manager for Alloy Rods Co. was recently announced. The region includes New Jersey, eastern Pennsylvania, New York and all New England states with sales office and warehouse locations in Newark and Boston, Mass.

Mr. Clark is a graduate of the University of Florida where he was awarded a B.S. degree in finance and marketing. He has been associated with sales management and administration in various fields including metal and plastic tubing and mechanical rubber products.

Ballard Sales Engineer

Harold D. Ballard AWS has joined the sales force of The Lincoln Electric Co.'s Milwaukee office and will cover Milwaukee and the southern part of Wisconsin. Mr. Ballard, a mechanical engineer from Purdue University, holds an M.B.A. from Wharton Business School and completed a one-year training program.

Mr. Ballard replaces Donald E. Bly who has been transferred to Appleton, Wis., to cover Northern Wisconsin and the Upper Peninsula of Michigan. Mr. Bly has been with Lincoln for eight years, having spent five years at the factory and three years as a welding engineer in Milwaukee, Wis.

Groening Made Sales Manager

Robert E. Groening [AWS] has been appointed general sales manager of United Welders, Inc., Bay City, Mich., according to an announcement by Clyde F. Kaunitz, President. After five years with the company, Mr. Groening will now be responsible for sales efforts as the company increases its emphasis on special-purpose automated welding and processing machines.

Following graduation from the General Motors Institute, with an M.E. degree, Groening was employed as a tooling and welding engineer, and later as a plant manager. He came to United after one year on the central engineering staff of Ford Motor Co.

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For details, circle No. 12 on Reader Information Card

Brigance, Gubbins, Marrero Assume Duties

Modern Engineering Co., St. Louis, Mo., announces the appointment of Roy Brigance AWS and Vint Gubbins AWS as factory sales representatives for its Meco oxyacetylene welding and cutting apparatus and industrial regulator divisions.

Mr. Brigance will work with distributors in Ohio and adjacent areas with headquarters in Cleveland. Mr. Gubbins will have the Illinois territory which includes parts of adjacent States.

Mr. Federico Marrero has just joined Meco's export division to work with distributors in Latin American countries.

Cox Appointed Manager

Standard Steel Corp. has named Vice-President James E. Cox as general manager of its Cambridge division in Lowell, Mass., executive-Vice-President C. N. Rees has announced.

Standard Steel's Cambridge division designs and manufactures cryogenic equipment for transporting, storing and handling low temperature liquefied gases for commercial and defense use.

Cox formerly was executive vice president of Hofman Laboratories, Inc., at Hillside, N. J. He is a

graduate of the University of Michigan's college of engineering, and has done advanced engineering study at Pennsylvania State University.

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A-735. Welding Engineer or Plant Manager. B.S. in Metallurgy. Seventeen years' experience in welded fabrication, alloy and stainless steels, automatic, manual. Good background in shop and field fabrication.

A-736. Welding Engineer. University graduate, 39, married. Eight years' experience in welding metallurgy and design for high-pressure vessels, liquid oxygen storage tanks, crystallizers, heat exchangers, etc.; preparation of specifications and manufacturing instructions, supervision of all welding processes. Present in charge of welding, X-ray, heat treating and testing laboratory. Capable of developing new methods and techniques. Desires a management level position offering challenge and scope for advancement.

A-737. Welding Engineer. M.S. degree. Married. Ten years' diversified experience in resistance and fusion welding research. Several publications in these fields. Main interest in stainless and high temperature alloys. Last 5 years in supervisory capacity. Résumé on request.

A-738. Manufacturing and Management Consultant. Available on fee basis for providing assistance in metals joining, manufacturing, materials problems, quality control, inspection and related aspects of cost reduction and product integrity. International reputation. Services available to smaller companies.

INSTRUCTIONS FOR PROSPECTIVE AUTHORS

Authors who plan to submit papers for publication in the Welding Journal are invited to send for a free copy of the booklet "Instructions and Suggestions for Authors." All requests should be addressed to Editor, Welding Journal, American Welding Society, 33 W. 39th St., New York 18, N. Y

OBITUARY

C. J. Hogan Dies at Thirty-three

C. J. Hogan, district sales manager for Miller Electric Manufacturing Company, Inc., passed away at his home in West Covina, Calif., on May 16th, at the age of 33 years.

Hogan, a World War II veteran, was born in Brooklyn, N. Y. After his discharge from the Army, he attended Harvard University and was graduated in 1946.

C. J. Hogan

After being associated with Union Carbide and Carbon Corp. in the foreign department, and with National Cylinder Gas Co., "Connie" Hogan joined Miller Electric in June of 1953. A member of AWS, he was assistant sales manager in the home office at Appleton, Wis., at the time of his transfer to California in 1956.

EMPLOYMENT OPPORTUNITY FOR ENGINEER

AWS is seeking an engineer to join Headquarters' Technical Staff as Assistant to the Technical Secretary.

Here are the duties—

Working with AWS technical committees in gathering and correlating technical data; preparing minutes, reports and other records of committee activities; editing standards for publication as completed.

Disseminating technical information in answer to inquiries from industry.

Related duties as assigned.

Here are the qualifications—

Ability to work with technical men at all levels in a cooperative manner. This is necessary to deal successfully with committee personnel, AWS members and the general public.

A degree in engineering, any branch.

At least three years' experience in engineering work, preferably in welding or allied fields.

Here is an opportunity—

The man we are seeking has initiative and imagination and is interested in becoming familiar with welding in all its aspects and for every type of application. Salary will be commensurate with qualifications and experience.

If interested in being interviewed for this position, send a resume* of your education, experience and personal background to

Technical Secretary
American Welding Society
33 West 39th Street
New York 18, N. Y.

* Will be held confidential.

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C

2,916,815—Method of Welding or Brazing Aluminum—Teunis Donkervoort, Noordwijk a. Zee, Netherlands, assignor to Vennootschap onder Firma Exploitatie-Onderneming van Octrooirechten Noortich, Noordwijk, Netherlands, a partnership of Netherlands.

The present patent is on a method of brazing or welding a member made from aluminum and aluminum alloys to a member made from an alloy of copper, iron, steel and the like, and in this method no flux or inert shielding gas is used. The method comprises effecting the brazing or welding with a material consisting of 76.2–85% by weight of aluminum, 12–19% by weight of silver and 3–4.8% by weight of silicon.

2,917,618—Apparatus for Feeding Welding Electrodes— Ronald F. Brennen and James A. Bucci, Brooklyn, N. Y.

The apparatus disclosed is for feeding electrodes and includes a holder with a handle extending therefrom. A clamp is present on the holder to grip one end of the electrode and the other end of the electrode extends forwardly of the holder to a point adjacent the work. Cam and transverse plate means connect to the clamped electrode for advancing the electrode a predetermined distance so that the amount to be consumed may be accurately established.

2,918,563—Welding Devices for Metallic Pieces—Jean A. Ternisien, La Celle St. Cloud and Michel Dupont, Paris, France, assignors to Trefileries et Laminoirs de Precision Gilby-Fodor (Societe Anonyme), Seine-&-Oise, France, a French company.

A new welding device is for use with metallic pieces liable to absorb gases contained in the atmosphere and the device includes a chamber having an open face and a shell pervious to gases extending over the face and closing the chamber but being formed to provide a cavity wherein a piece to be welded may be placed. Thus the piece to be welded is placed in the cavity and is at least partially surrounded by the shell and a permeable gas absorbing material is interposed between the chamber and the shell. Another means is present so as to introduce into the cavity between the piece and the shell a protective gas that is inert with respect to the piece to be welded.

2,918,564—Pressure - controllable Rotary Welding Electrodes—John D. Russell, Hollywood, Calif.

Russell's patent is on an apparatus assembly including a conductive electrode roller element which is mounted in side-by-side relation with a stop roller on a common shaft. Resilient means are present in the apparatus assembly so that the electrode roller element can be shifted transversely of the shaft means but with such roller element still protruding radially beyond the stop roller.

2,919,335—Induction Welding of Metallic Pipes—Frederick C. Shaughnessy, New York, N. Y., assignor to Consolidated Edison Co. of New York, Inc., New York, N. Y., a corporation of New York.

Shaughnessy's patented apparatus is for butt welding the ends of metal tubes together. The apparatus includes induction heating means to bring the tube ends to welding temperatures and other means press the tube ends together. Vibrating means are present for vibrating the tube ends during the welding thereof.

2,919,341—Multi-gas Sigma Welding—Donald W. Roth, Kenmore, Kenneth L. Thomas, Buffalo, and Charles R. McKinsey, Niagara Falls, N. Y., assignors to Union Carbide Corp., a corporation of New York.

In this process of sigma welding steel with a consumable electrode, initially a welding arc is established between the electrode and the steel work piece to be welded. The welding arc is shielded with an inner annular stream of suitable gas and an outer annular stream of carbon dioxide gas where the relationship of the streams of gases is such that they merge into streamlined relation immediately after their discharge into the open air. The gas in the inner stream is relatively lighter than that of the outer stream and is selected from the class consisting of argon alone, a mixture of argon and oxygen, a mixture of argon and helium, a mixture of argon, helium and oxygen, a mixture of argon and carbon dioxide, and a mixture of helium, argon and carbon dioxide.

2,919,342—Welding of Strip Ends and the Like—Fred Kohler, New York, and Walter C. Rudd, Larchmont, N. Y., assignors to Magnetic Heating Corp., New Rochelle, N. Y., a corporation of New York.

The present process is for welding an elongate edge of one metal portion to an elongated edge of another metal portion. These portions are positioned with their edges extending along each other in close but spaced relation and a heating current of a frequency of about 50,000 cps or higher is conducted onto the elongated edge of the first of the portions to flow therealong and thence is conducted to the other of the elongated edges to flow back therealong and then to the source. Special current control members are associated with the metal portions for the desired flow action. After the portions are heated substantially concurrently to welding temperature, they are brought into contact under pressure for welding action.

2,919,343—Welding of Strips—Wallace C. Rudd, Larchmont, N. Y., assignor to Magnetic Heating Corp., New Rochelle, N. Y., a corporation of New York.

Rudd's patent comprises an improvement upon the invention disclosed in Patent No. 2,919, 342. In Rudd's process, the heating current may have a frequency of the order of 100,000 cps or higher, and Rudd particularly provides a member such as magnetic masses having a low loss factor and a high volume resistivity in positions closely spaced from the metal portions and somewhat spaced back from the edges to increase the impedance to the current flowing along the paths spaced back away from the edges and hence causing the current to be concentrated on the edges as desired.

2,919,487—Method of Forming Clad Metal Plates—Lloyd C. Stiles, Chicago, Ill., and Robert C. Bertossa, Birmingham, Ala., assignors to Chicago Bridge & Iron Co., a corporation of Illinois.

A method of forming a sandwich structure for cladding is disclosed by the present patent. A sandwich is assembled from a lower base plate, a brazing metal, a cladding plate overlapped by the base plate, a second cladding plate sealed to the first at its periphery, a second layer of brazing material over the second cladding plate and then an overlapping upper base plate. The peripheral edges of the base plates are sealed together, and a vacuum is established between the base plates and the assembled sandwich and thereafter the sandwich is heated to effect the desired brazing action without effecting the seal between the two cladding plates.

2,919,984—Brazing Alloy—Rene D. Wasserman, Stamford, Conn., and Joseph F. Quaas, Island Park, N. Y., assignors to Eutectic Welding Alloys Corp., Flushing, N. Y., a corporation of New York.

The new brazing alloy consists of the following materials in the percentages indicated: Cadmium, 90 to 94% by weight; silver, 4 to 5% by weight; zinc, 3 to 4.75% by weight.

2,920,181—Electric-arc Deoxidized-Metal Deposition—Harry E. Rockefeller, Bronxville, and Jack L. Wilson, Niagara Falls, N. Y., assignors to Union Carbide Corp., a corporation of New York.

In this process, a bare metallic wire electrode and a metallic workpiece are connected to a source of electric power and the electrode is fed toward the workpiece to establish and maintain an arc and deposition zone with the workpiece. A stream of shielding gas is supplied and has suspended therein a powdered mixture substantially free of slag forming fluxing components and containing essentially a deoxidizing component and a magnetic component. The particles are magnetically carried by the wire electrode to the deposition zone. The rate of suspending the powdered mixture in the stream is coordinated with the rate of fusion of the electrode so that one can reduce substantially the flow of the shielding gas stream necessary to protect the process from contamination by atmospheric air.

2,920,182—Apparatus for Electric Resistance Welding Two Tubes to a Spacer Strip—Norman R. Johanson, Alliance, Ohio, assignor to the Babcock & Wilcox Co., New York, N. Y., a corporation of New Jersey.

Johanson's patent is on specialized apparatus for resistance welding a pair of preformed metal tubes to a longitudinally extending metal web where the web is positioned in substantially the common diametric plane through the tubes and with the tubes being welded to the opposite edges of the web.

2,920,210—Welding Generator Attachment for Motor Vehicles—Lovell H. May, St. Paul Minn.

May's patent is on a welding generator attachment for a motor vehicle wherein the motor vehicle has an accessible power shaft provided therein to which a welding generator can be attached for drive action by the apparatus of the invention.

2,922,019—Welding of Lengths of Tubing—Wallace C. Rudd, Larchmont, N. Y., assignor to Magnetic Heating Corp., New Rochelle, N. Y., a corporation of New York.

Rudd's new method relates to the welding of opposed longitudinal edge portions of successions of metal elements to one another. In the process, the metal elements are passed by a weld point where spaced edge portions of the metal elements are forced together for weld action. A V-shaped gap remains between the longitudinal edge portions of the element in advance of the weld point. The trailing edge of each metal element has a recess therein adjacent the line of the desired seam, and the forward end of the succeeding metal element has a projection for engaging this recess. Hence the following metal element and a spreader means positioned in advance of the weld point maintains the metal elements positioned with a gap between the longitudinal edges thereof until the metal element reaches the weld point.

2,920,183—MAGNETIC OSCILLATION OF WELDING ARC—William J. Greene, Scotch Plains, N. J., assignor to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

This patent relates to an electric arc-welding process wherein the metal of a consumable wire electrode is melted by the arc and transferred across the arc between the end of the electrode and the work in the form of drops. A novel portion of the process relates to creating a cyclically reversing magnetic field substantially transverse to the axis of the electrode at a reversal frequency such that the drop-transfer time across the arc is less than the time of one-half cycle to cause the arc and the drops transferring across the arc to be deflected alternately to one side and then to the other side of the axis of the electrode.

2,921,177—LOW-VOLTAGE PERCUSSION-WELDING APPARATUS—John S. Gellatly, La Grange Park, Joel R. Johnson, Chicago, and Amos L. Quinlan, La Grange Park, Ill., assignors to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

A percussive welding gun, including a frame, a first normally open gripping means pivotally mounted on the frame, and a second normally open gripping means fixed to the frame, is disclosed in the present patent. Other means are present to move the first gripping means toward the second gripping means and other means sequentially close the first and then the second gripping means and thereafter actuate the moving means to move the closed first gripping means toward the closed second gripping means.

2,921,222—ELECTRIC ARC-WELDING APPARATUS—David James Wilson Boag, Croydon, England.

Boag's patent is on an automatic-feed device for a consumable electrode where the arc-welding apparatus has an arc-current supply-circuit energized from one phase of a three-phase alternating current supply. The electrode drive rolls that engage and feed the electrode are driven through a differential gear having two input shafts individually connected to two drive motors provided therefor. A transformer is provided and has a primary winding connected to one phase of the three-phase current supply and has two secondary windings connected one to supply each of the two motors and a control winding also provided and arranged so that a current flowing therein serves to increase the output of one of the secondary windings while decreasing the output of the other. The control winding has applied thereto a first voltage of phase corresponding to one phase of the three-phase current supply other than the phase from which the arc circuit is energized. The control winding also has a second voltage applied thereto derived from the arc current supply circuit which varies progressively in magnitude and phase with variation of welding arc length.

2,922,870—THIN METAL WELDING METHOD AND APPARATUS—Jay C. Collins and Seth P. Jenkins, Fort Worth, Tex., assignors to General Dynamics Corp., San Diego, Calif., a corporation of Delaware.

A method of welding paper-thin sheets of stainless steel, titanium and similar metals to produce an aerodynamically smooth weld is disclosed. The method includes the steps of abutting the edges of the sheets to be welded throughout the length of the welding edges and clamping the edges in vertical alignment under uniform pressure. A low-current arc is applied at one end of the edges and a helium gas shield is applied uniformly along the underside of these edges. An argon gas shield is applied around this arc and the arc is subjected to a superimposed high-frequency current until ionization occurs and thereafter high-frequency current is removed and the argon gas shield is replaced with a helium gas shield. The resultant gas shield and arc are then moved progressively along the edges at a slow rate to assure welding penetration throughout the entire thickness of the edges. Heat is dissipated from the edges to prevent burning and warping thereof.

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Current Welding LITERATURE

For copies of articles, write directly to publications in which they appear. A list of addresses is available on request.

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Automatic Brazing Machine in Continuous Line for Assembling Heat Exchangers, N. L. Boisvert. *Indus. Heating*, vol. 26, no. 12 (Dec. 1959), pp. 2442–2444, 2446.

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Flame-Sprayed Contact Surfaces on Aluminum, D. K. Fox and C. L. Carlson. *Light Metal Age*, vol. 18, no. 1 - 2 (Feb. 1960), pp. 24–27.

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Aluminum Brazing Paste Saves $175,000 at Martin, D. Wernz, and M. Schwartz. *Steel*, vol. 145, no. 15 (Oct. 12, 1959), pp. 112–114.

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How Electroslag Welding is Used in Russia, A. B. Tesmen. *Metal Progress*, vol. 77, no. 2 (Feb. 1960), pp. 118–122.

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Welding of X56 Pipe, N. F. Blundell. *ASME*—Paper no. 59-Pet-12 (for meeting Sept. 20–23, 1959), 4 pp.

New Literature

Electrode Selection

A handy pocket-size card which gives application information on mild-steel arc-welding electrodes and explains how to identify them according to AMERICAN WELDING SOCIETY–American Society for Testing Metals classification is offered by Hobart Bros. Co., Troy, Ohio.

For your free copy, circle No. 51 on Reader Information Card.

Filler-rod Comparison Chart

Twenty-three NCG welding filler rods for use in welding nine different metals are listed along with competitive brands in a new comparison chart available from National Cylinder Gas Division of Chemetron Corp., 840 N. Michigan Ave., Chicago 11, Ill.

The chart (N-126) gives the names and numbers of rods sold by NCG and by 22 other major suppliers for welding steel, high-tensile steel, low-alloy steel, alloy cast iron, cast iron, stainless steel, aluminum, bronze and flux-coated bronze.

The chart also illustrates and describes each of 10 different fluxes made and distributed by NCG, and gives a guide for ordering the right amount of flux for the rod to be used.

For your free copy, circle No. 52 on Reader Information Card.

Noncritical-pipe Welding

Basic information concerning arc-welding techniques for small diameter piping is contained in the Lincoln Electric Co. bulletin 2112.3 called *Arc Welding Small Diameter, Non-Critical Piping*. The bulletin lists the advantages of welded piping installations and describes the calculation of welding costs with a chart. Recommendations are made for the best type of electrodes.

For your free copy, circle No. 53 on Reader Information Card.

Electron-beam Welding

A 12-page brochure has been released by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y., on its newest welding technique, electron beam welding. This method, which welds by the direct bombardment of metal with highly accelerated electrons in a vacuum chamber, has special significance in regard to the newer metals and alloys which are difficult or impossible to weld with conventional techniques.

Illustrated throughout, the brochure covers all of the salient features of electron-beam welding, how the process operates, the principal advantages and the equipment required. A full-page schematic drawing of the electron beam gun is of particular interest.

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Thermit Welding Method

Information on Thermit welding of reinforcing steel for heavy concrete construction is given in a data sheet available from Thermex Metallurgical, Inc., Lakehurst, N. J. A new welding process developed specifically for this type of work is described and welding procedures are illustrated and explained in detail.

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Propeller Repair Shop

The *Copper and Brass Bulletin* for May ran a brief one-page description of how an Erie, Pa., veteran welder set up a propeller-repair shop. Bronze-alloy brazing rods are used for build-up of damaged parts—and business seems good.

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Large Projects Reviewed

Featuring articles on the new Boston tunnel, a modular nuclear-power plant (for quick erection) and a 410-mile oil pipe line through French Algeria, the *Alco Review* spring-summer edition, covers a variety of welding. Published by Alco Products, Inc., 530 Fifth Ave., New York 36, N. Y.

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Chart Shows Aluminum Filler-metal Selection

Said to be the only one of its type available, a filler-metal selection chart that shows the correct filler choice based on parent metal and service requirements is offered by Aluminum Co. of America, 743 Alcoa Building, Pittsburgh, 19, Pa.

The filler alloys are grouped with 14 parent-metal combinations and are rated according to welding ease, strength, corrosion resistance, service temperature, anodizing color match and ductility.

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Background Survey on Resistance Welding Machines

A 24-page brochure offered by The Taylor-Winfield Corp., Warren, Ohio, has photographs of 268 welded products and 20 photographs of welding units and laboratory facilities. Included are actual case histories showing how modern resistance-welding machines are selected or specially engineered for the needs of particular welded products.

For your free copy, circle No. 59 on Reader Information Card.

Design Advantages in Brazing

A 4-page circular, "Brazing News" No. 83, has been issued by Handy and Harman, 82 Fulton St., New York 38, N. Y. Five examples are illustrated and explained whereby particular design problems have been solved by brazing techniques. Intended to serve as a guide to indicate some methods of approach to cost-saving and dependability by brazing, the bulletin stresses the achievements of freedom, flexibility, facility and function. The information offered concerns this company's silver brazing product, "Easy Flo" and further literature is available covering the subject.

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Ultrasonic Flaw Detection

Available from Branson Instruments, Inc., Stamford, Conn., is an 8-page illustrated bulletin describing the advantages of their pulse-echo instrument, the Sonoray 5 flaw detector. Schematic diagrams illustrate the principles of operation and suggested methods for testing particular conditions are given. Various types of beam-path interruptions are shown together with the corresponding trace on the cathode-ray tube to illustrate "good' and "bad" interpretations. Detailed specifications of parts and performance characteristics are also given. Short descriptions are also given for resonance-type thickness gages and ultrasonic cleaning equipment made by the company.

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55,000!

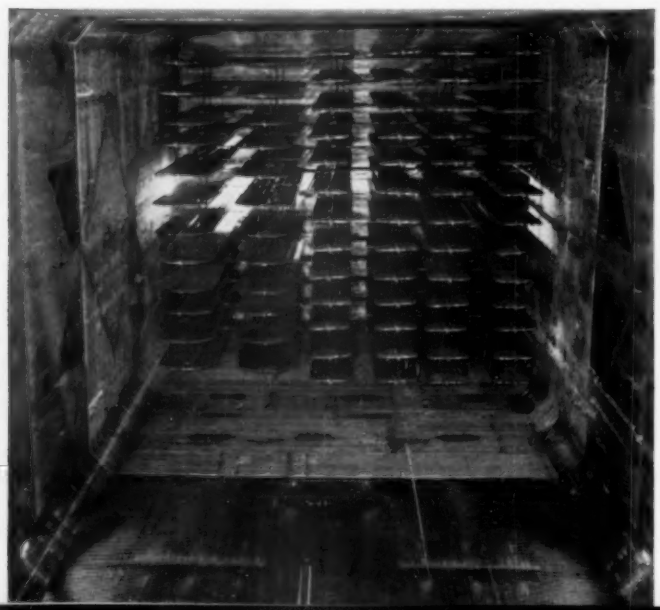
HIGH STANDARDS AND QUALITY ELECTRODES FEATURE CONSTRUCTION OF WORLD'S HIGHEST PRESSURE STEAM GENERATOR.

The Eddystone Station of the Philadelphia Electric Company is a milestone in power station engineering and operating efficiency.

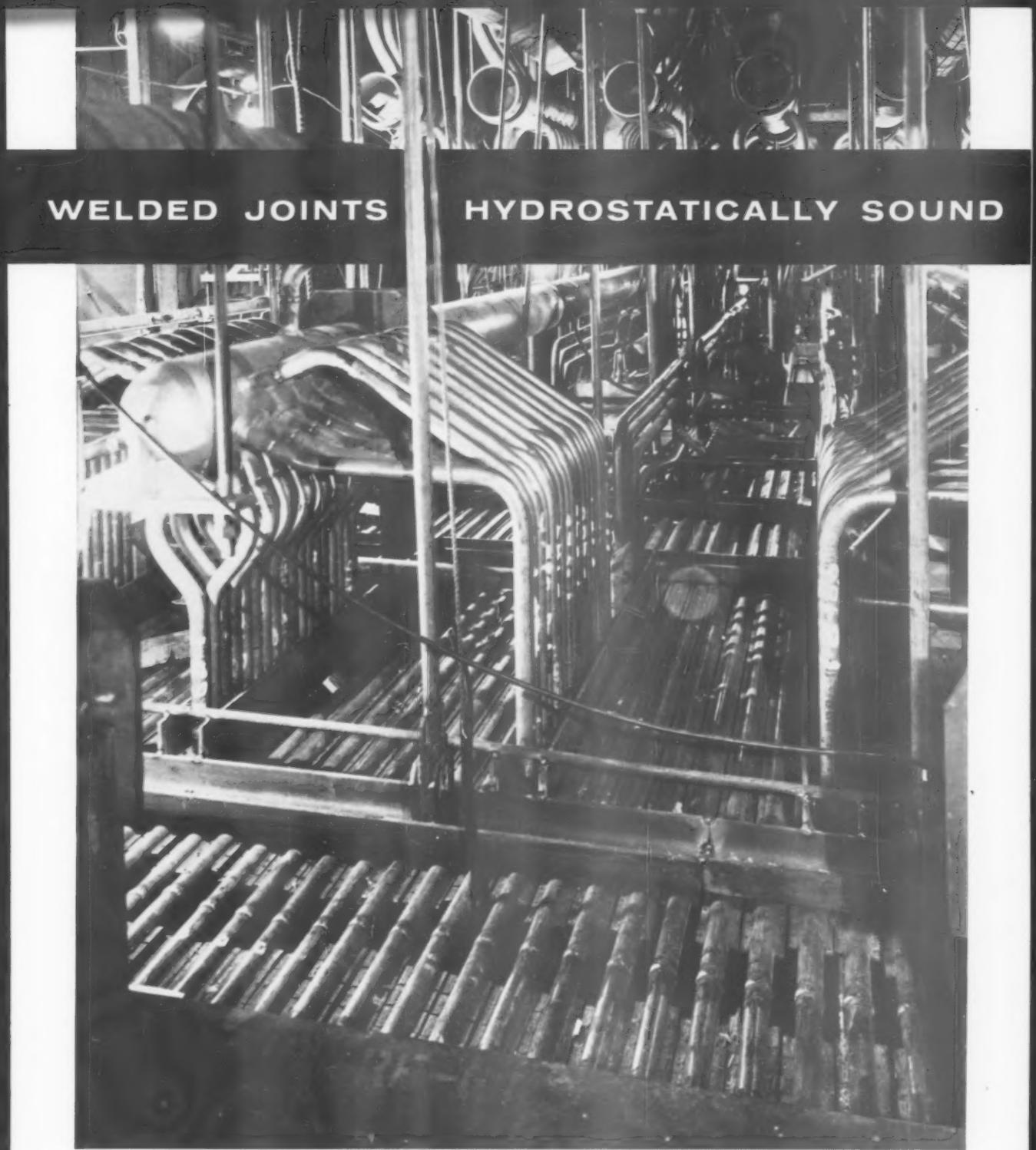
Situated on the banks of the Delaware River south of Philadelphia, Eddystone is the first power station in the world designed to produce steam at the supercritical pressure of 5,000 pounds per sq. in. and a temperature of 1200° F. This breakthrough in the commercial generation of electricity is expected to set a new world's record for power station efficiency by producing a kilowatt hour from 2/3 pound of coal.

55,000 welds were used to fabricate the hundreds of miles of tubing and piping used in the construction of the steam generating unit. Approximately 25,000 of these were field welds made at the construction site. The extreme operating pressure and temperature necessarily required unusually high weld metal quality and reliability from the electrodes selected. For the field welds, Combustion Engineering, designer and manufacturer of Eddystone's No. 1 boiler, specified Arcaloy types 316 and 347 stainless steel electrodes for the chromium-nickel material, Atom-Arc 8018CM and 9018CM iron powder low hydrogen electrodes for the chrome-moly grades and Atom-Arc 7018Mo for the carbon-moly grades. Continuous visual inspection was conducted as all welding proceeded. Dye penetrant and X-ray inspection of welds were used throughout the erection of the boiler. When the boiler had been completely welded, it was hydrostatically tested at 8,000 psi. pressure. All of these tests and inspections failed to show one defective or leaking field weld.

These dynamic results mirror the experiences of many leading fabricators throughout the country. Like Combustion Engineering, they have proven conclusively that X-ray quality weld metal of Alloy Rods Company electrodes increases the efficiency of their welding operations. They have learned from experience—you can profit from their experience. Specifying your electrode requirements from our extensive line of quality alloy arc welding electrodes is the one sure guarantee of satisfaction. Alloy Rods Company, York 3, Pennsylvania.



The steam producing heart of the station is a C-E Sulzer Monotube Steam Generator, designed and manufactured by Combustion Engineering. This unit is 12 stories high, 100 feet across, and 75 feet from front to back. 170 miles of all-welded tubing and piping, low-chromium and chromium-nickel material, went into the unit's fabrication.



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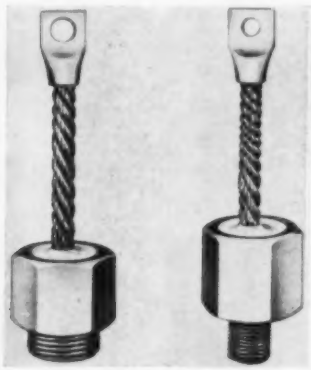
Silicon Rectifiers

Several series of recently developed silicon power rectifiers are announced by Syntron Co., 258 Lexington Ave., Homer City, Pa.



The characteristics of these rectifiers, together with a description of numerous other Syntron products, are described in a 68-page catalog (No. 605) recently published.

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Magnetic-flux Welding

Two pieces of literature describing the Unionarc welding process are available from Linde Co., 270 Park Ave., New York 17, N. Y. The process is a semiautomatic flux-and-CO_2-shielded method for welding steel.

A 16-page catalog (F-1379) describes the complete line and a 12-page booklet (F1376) contains illustrated case histories of economies achieved in numerous applications.

For your free copy, circle No. 62 on Reader Information Card.

Electrode Catalog

Shober, Inc., 900 W. Weber Ave., Stockton 3, Calif., offers a 15-page catalog giving all details and descriptive data for 18 electrodes. Included are electrodes for welding mild steel, low-alloy high-tensile steel and stainless. Iron-powder low-hydrogen and hard-surfacing electrodes as well as welders' accessories are described.

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Air–Carbon-arc Process

A small folder describing the relative merits of carbon and graphite in electrodes used for air–carbon-arc gouging is available from Arcair Co., P. O. Box 431, Lancaster, Ohio. Copperclad and other types of electrodes are discussed and current settings are listed.

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Hard-surfacing Electrode

A data sheet (No. A) giving complete details on Hardalloy 44, a new hard surfacing electrode, is available from the McKay Co., 1005 Liberty Ave., Pittsburgh 22, Pa.

The electrode is designed for severe impact and abrasion. As deposited on C1020 steel, the hardness is reported as Rockwell C 40-45; on 12–14% manganese steel, 33–45 Rc. It work hardens rapidly to 52 Rc. It is intended for bucket lips and teeth, hammer mill hammers, crusher screens and similar equipment.

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Welding-process Selection

A 5-page reprint of an article "Which Welding Process for the New Metals" by I. D. Holster is available from Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. The article reviews problems in joining the newer metals and alloys used in aircraft and missile design.

For your free copy, circle No. 66 on Reader Information Card.

Welding-machine Bulletin

A combination news bulletin and welding machine catalog, the "Memco News" for February and March 1960 is available from the Miller Electric Manufacturing Co., Inc., Appleton, Wis. Featured are the specifications of several newly designed machines.

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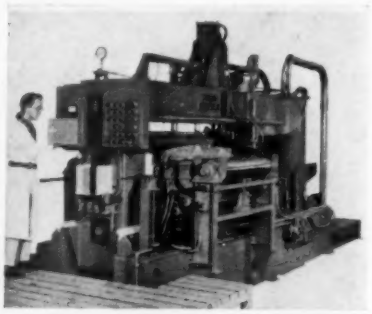
Steel Strip Welding Equipment

The four-page bulletin "Weld-It" (No. 603) published by the Taylor-Winfield Corp., Warren, Ohio, illustrates typical examples of the



machines made by this company for welding steel strip. Various types of continuous strip processing call for narrow-lap (mash), wide-lap, flash-butt or arc-welding equipment. The basic types are briefly described.

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Electron-beam Welding

In addition to several well-illustrated articles on resistance welding techniques, "Resistance Welding at Work," vol. 5, no. 7, describes Sciaky's electron-beam welding unit. Sciaky Bros., Inc., 4915 W. 67 St., Chicago 38, Ill.

For your free copy, circle no. 69 on Reader Information Card.

Utility Welding Machines

Four "Sureweld" utility arc welders, for use where both a-c and d-c welding currents are needed, are described in two new bulletins available from National Cylinder Gas Division of Chemetron Corp., 840 N. Michigan Ave., Chicago 11, Ill.

Models SU-185 and SU-185P are described in bulletin NH-176. These welders are designed for use in shops and garages and on factory production lines and farms.

Bulletin NH-177 presents models SU-255 and SU-255P for shops and factories.

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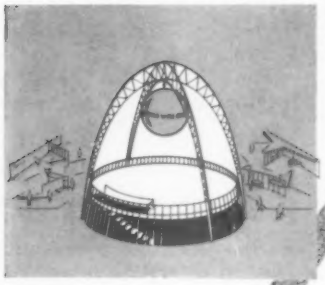

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If you've kept up with your reading, you should now know that five points of especial interest have been developed by the survey requested by a leading advertising agency. Because these 5 points are especially interesting to future advertisers in the Welding Journal, we thought we'd stack them up together to give you a chance to compare them with any magazine in the welding field to determine where you can get the most from the advertising dollar.

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WELDING JOURNAL

Aluminum Quarterly

"The Aluminum Bulletin" published by the Aluminum Association, 420 Lexington Ave., New York 17, N. Y., contains short articles on new and interesting applications of the metal.

For your free copy, circle No. 71 on Reader Information Card.

Gas Metal-arc Welding

A 16-page catalog (F-1393), covering their manual gas metal-arc welding equipment, is available from Linde Co., 270 Park Ave., New York 17. N. Y.

Three styles of the Sigmatic welding process are described: frame, sled and cart types. Listed also are torches for different applications as well as the complete line of welding controls.

For your free copy, circle No. 72 on Reader Information Card.

Resistance-welding Tips

A 24-page catalog on Tuffaloy resistance welding tips, tip holders and alloys has been released by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. This is the first resistance welding alloy catalog to utilize the new "RW" taper numbering system for specifying spot-welding tip size, as proposed by the Resistance Welding Alloy Assn. The elimination of confusing Morse taper numbers, plus the introduction of a convenient new size tip, the 6 RW (3/4 in. diam) makes the Tuffaloy catalog easier to use.

For your free copy, circle No. 73 on Reader Information Card.

Automatic Arc Welding

An 8-page bulletin (8-513A) describing 14 special, high-production, automatic, arc-welding machines, with emphasis on production rates is obtainable from the Taylor Winfield Corp., 1048 Mahoning Ave., Warren, Ohio.

For your free copy, circle No. 74 on Reader Information Card.

Pipe-line Construction

In a colorful, 36-page brochure, H. C. Price Co., Price Tower, Bartlesville, Okla., tells the well-illustrated and dramatic story of several thousand miles of pipe-line construction and the people who did the work.

For your free copy, circle No. 75 on Reader Information Card.

Brazing Preforms

A well-prepared 16-page booklet that treats the design and application of numerous types of brazing preforms in a variety of alloys is offered by Lucas-Milhaupt Engineering Co., Cudahy, Wis.

For your free copy, circle No. 76 on Reader Information Card.

Titanium Fact Sheet

A chart giving the designations and properties of various pure and alloyed titanium is offered by Nooter Corp., 1400 S. Third St., St. Louis 66, Mo. Included are a listing of compositions, commercial and military code designations, metallugical and physical data.

For your free copy, circle No. 77 on Reader Information Card.

Seamless Welding Fittings

A 12-page illustrated bulletin describing seamless-type welding fittings has been published by Midwest Piping Co., Inc., 1450 S. Second St., St. Louis 4, Mo.

Bulletin No. 60-C also describes new seamless manufacturing operations, dimensional and metallurgical control processes and testing procedures used by the company.

For your free copy, circle No. 78 on Reader Information Card.

Liquid-gas Bulk Stations

Air Reduction Sales Co., 130 E. 42nd St., New York 17, N. Y., has just issued a six-page folder covering the company's liquid-gas storage and conversion stations for installation on customer property. These stations are used to supply oxygen, nitrogen and argon to medium and large volume users of these industrial gases.

For your free copy, circle No. 79 on Reader Information Card.

Now... programmed welding automation from P&H!

with infinitely versatile time-amperage controls.

P&H TAPE-PROGRAMMING completely automates the fusion process and is far superior to human control. Additional channels on tape and reader provide precise control for rotation, wire-feed, gas and water flow, and other related functions.

P&H MOTORIZED RHEOSTAT permits pre-setting of upslope, welding cycle, and decay at intervals of 6 to 50 seconds—and controls them at exact values. Weld time can be pre-set or controlled manually.

P&H AUTOMATIC SPOT-GUN CONTROL enables operator to pre-set time interval and heat for starting, welding, finishing, and post-flow of gas and water in spot-gun welding. "Add-on" units for existing welders — integral in new machines.

For example, the new P&H motorized rheostat and sequence timer enable you to weld Space Age and other super-critical metals *automatically!* You just dial the pre-calculated heat-time values and press the start button. The control responds with the exact cycles you need for precisely controlled upslope, welding cycle, and decay. The result: perfectly controlled super-critical welding without thermal shock or cracking.

Another modern development is the new P&H punched-tape control for production welding. This industry "first" enables you to tape your jobs today — and weld tomorrow or next month. You can handle more work and get the same top-quality welds regardless of who operates the unit.

Find out today what P&H time-amperage controls can do for you. Send for Bulletin W-155.

HARNISCHFEGER P&H
Milwaukee 46, Wisconsin

Export Division:
4329 W. National Ave., Milwaukee, Wis.

P&H welding equipment is manufactured and sold in Canada by REGENT EQUIPMENT MANUFACTURING COMPANY, Ltd.
455 King St. West • Toronto, Ontario, Canada

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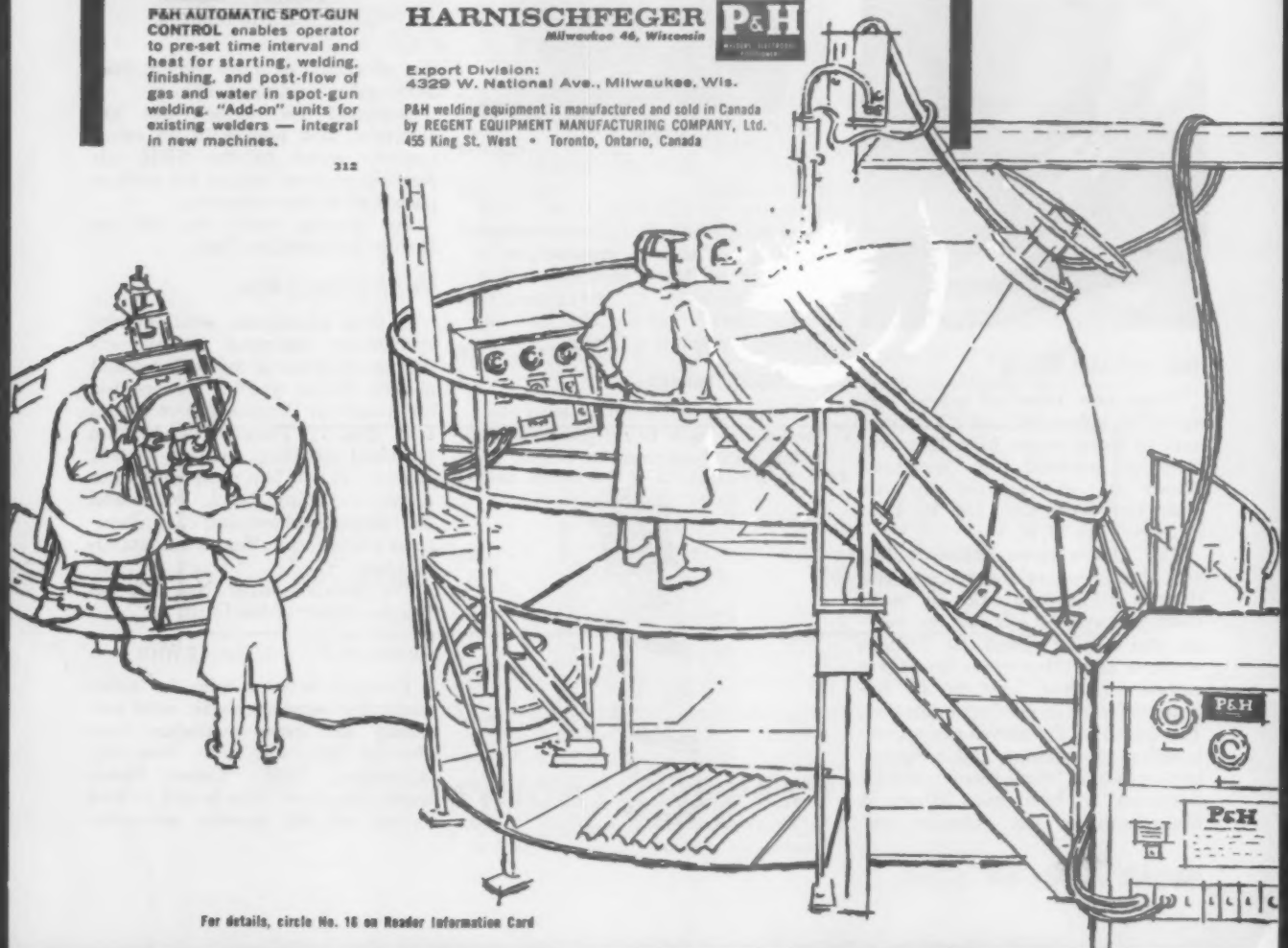


For details, circle No. 16 on Reader Information Card

New Products

Wide-vision Goggles

Welding goggles that are said to solve a serious optical safety problem by eliminating dangerous blind spots are announced by National Cylinder Gas Div. of Chemetron Corp., 840 N. Michigan Ave., Chicago 11, Ill. The Seesall Series FS-250 goggles have angled lens, available in three shades, which provide wide vision and enable the welder or chipper to take in the entire work area with just a slight tilt of the head.

The goggles fit easily over all spectacles, allow indirect ventilation, and have a flexible leather protective nose guard, according to NCG.

For details, circle No. 101 on Reader Information Card.

Heat-resistant Gloves

Three new types of gloves, designed to reflect 90% of all radiant heat in work where high temperatures are involved, have just been placed on the market by Air Reduction Sales Co., 150 E. 42nd St. New York 17, N. Y.

The gloves have leather palms and aluminized asbestos backs and thumbs which are said to make them particularly suitable for welding and cutting operations, furnace work, or any other operation where extreme radiant heat is an important factor in efficient operation. The backs of the gloves are a combination of asbestos and a special heat resistant fabric (Scotch-shield) developed by Minnesota Mining & Manufacturing Co. Similar material is used in the suits to be worn by Astronauts, according to Airco.

The three styles are: a five-finger carpincho leather glove; a one-finger mitten of green heat-resistant leather; and a five-finger glove of green heat-resistant leather. All three types will have aluminized backs (excluding gauntlet) and thumbs. They are available either lined or unlined.

For details, circle No. 102 on Reader Information Card.

Carbon Electrodes

The Arcair Co., Lancaster, Ohio, has announced an improved carbon-type electrode "grade Q" used for metal removal. The higher current densities now in common use

with the $^1/_2$-, $^5/_8$- and $^3/_4$-in. diam electrodes are said to have caused spalling. The new composition is reported to have eliminated this condition.

For details, circle No. 103 on Reader Information Card.

Electrode Package

Low-alloy and stainless-steel electrodes are now being packaged in a laminated-ammunition-board, asphalt and foil container by Hobart Brothers Co., Troy, Ohio. Named Sealpak, the container has a tube shape and a metal cap-type lid. The lid has a recessed rim which provides a tight closure against moisture. Between the outer and inside wall of the container is a sheet of aluminum foil. This, plus an outer aluminum foil wrap and asphalt provides an excellent moisture barrier seal.

For details, circle No. 104 on Reader Information Card.

Welding Machine for Indoor Use

Taking advantage of the elimination of costly weatherproofing, the Miller Electric Manufacturing Co., Inc., Appleton, Wis., emphasizes

SILVER STAR RECTIFIER TYPE D-C WELDER

the economy of their Silver Star d-c rectifier welding machines.

Designed for indoor use exclusively, this line is in all other respects equal to the SRH all-weather models—except for savings passed on to the customer.

For details, circle No. 105 on Reader Information Card.

4043 Aluminum Wire

A 4043 aluminum welding wire specifically designed as an all-purpose filler metal for both gas and electric fusion welding is reported by American Brazing Alloys Corp., P.O. Box 11, Pelham, N. Y. Its principal alloying element is 5% silicon. It will join most aluminum alloys including 5052, 6053 and 6061wrought alloys and cast aluminum alloys, according to the manufacturer.

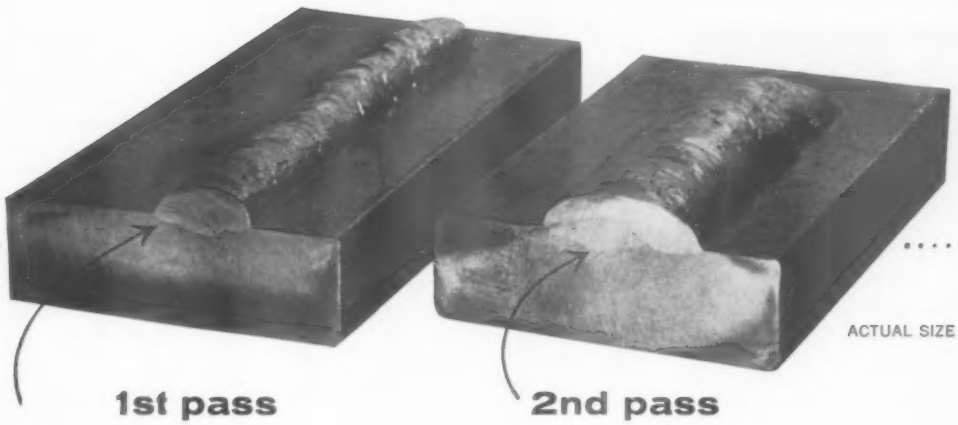
For details, circle No. 106 on Reader Information Card.

Automatic Hard-surfacing Wire

Coils of tubular wire for automatic and semiautomatic hard surfacing are now available from Rankin Mfg. Co., P.O. Box 631, Alhambra, Calif. Called Ranomatic, the cored wire is said to feed evenly on all popular semiauto-

STOODY BUILD-UP

(Iron Powder Coating)



Compare the new Stoody Build-Up with any other material of this type. It gives you:

SPEED.....15% to 50% faster deposit rate

BUILD-UP.....Higher—with sound deposits

ECONOMY.....High welding efficiency gives lower cost per pound of deposit

WELDABILITY.....Stable arc—low spatter—less smoke

OTHER FEATURES....Higher tensile strength—low crack sensitivity—excellent machinability

Use Stoody Build-Up for

- Shafts (to be machined)
- Gear Teeth
- Sprockets
- Tractor Rails
- Churn Drills
- Build-up on carbon steels for hard-facing overlay

See your Stoody dealer for complete information (check the Yellow Pages of your phone book) or write to

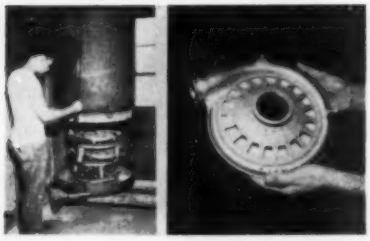
STOODY COMPANY
11986 E. Slawson Ave., Whittier, Calif.
For details, circle No. 17 on Reader Information Card

matic machines. Alloying elements carried in the core are reported to give results equal to the company's manual line of hard-surfacing rods. Types "A," "B-X," "C" and "D" are available.

For details, circle No. 107 on Reader Information Card.

High-quality Brazing

Unusually close dimensional tolerances in a stainless steel compressor turbine can be achieved through furnace brazing, according to the Morrisville, Pa., plant of Stainless



Processing Div. of Wall Colmonoy Corp. The turbine is a critical part in the air conditioning system on the B-58 Hustler aircraft. More than 60 separate pieces are simultaneously brazed into place in a pure dry hydrogen furnace at 2150° F.

For details, circle No. 108 on Reader Information Card.

Gas-shielded Units With Handy Mounts

Linde Co., Division of Union Carbide Corp., announces a line of "Sigmatic" welding machines for consumable-electrode inert-gas welding. Three mountings of standardized components are available: SWM-11 frame-type unit; SWM-12 sled-type unit; and SWM-13 cart-type unit.

The machines are said to use any shielding gas and the wire-feed units handle all popular wire diameters, either solid or cored. Torch designs are available in ratings from 200 to 500 amp, for continuous fusion welding ("spray arc" or "short arc") or spot welding. Optional features provide versatility.

For details, circle No. 109 on Reader Information Card.

Dial-feed Welding Machines

The precision dual-head AVB-3 dial-feed bench-welding machines, built by Precision Welder and Flexopress Corp., 700 Terrace Hilton Bldg., Cincinnati 2, Ohio, is designed for mass-production welding of small parts, particularly the high-speed assembly of small electrical components.

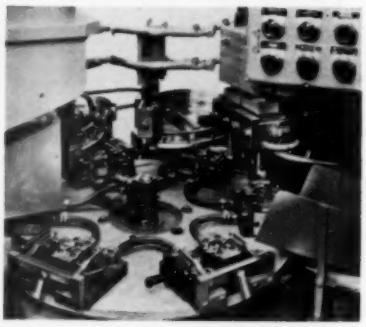


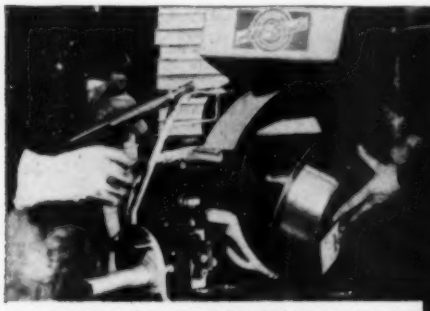
Photo shows the six-station Geneva dial-feed table tooled for welding spring contacts to two different styles of yokes for electrical outlets, one of which requires a forming operation (forming head is at left). The springs are series welded to the yokes by dual, adjustable, air-operated welding heads, mechanically interlocked and balanced. Parts are fed and ejected automatically. Production rate is 1500 to 1700 parts per hour.

For details, circle No. 110 on Reader Information Card.

Welding-rod Flux Binder

Intended as an alternative for bentonite in the coatings of basic or high-yield welding rods, a seaweed product, potassium alginate, is distributed under the name of Protanal EV 200 by Croda, Inc., 15 E. 26th St., New York 10, N. Y. The Norwegian manufacturer cites its value as a plasticizer and wet binding-agent for rod coatings.

For details, circle No. 111 on Reader Information Card.



Loading 10 lb. spool of #4043 aluminum wire at Michael Flynn Manufacturing Co., Philadelphia. Aluminum in this particular spool was used in welding curtain walls for skyscraper at 2 Broadway, New York City.

now you can get
All-State Spoolarc

SPOOLED ALUMINUM

in all grades, all types
precision layer level
wound on
1 lb. and 10 lb. spools

Wire goes from extrusion and light draw to ALL-STATE'S precision spooling machines where it is layer level wound for smooth, trouble-free welds.

Types available: 1100, 4043, 5052, 5154, 5183, 5356, 5556, 6061, 6063, *355,* 356, 716, 718.

Precision spooled in these sizes: .030, .040, 3/64, 1/16, 3/32, 1/8.
*down to 1/16 only

ALL-STATE *Spoolarc*® spooled aluminum wire meets federal and industry specifications. Spools are sealed in polyethylene bags plus desiccant to retain top quality from spooling machine to welding machine.

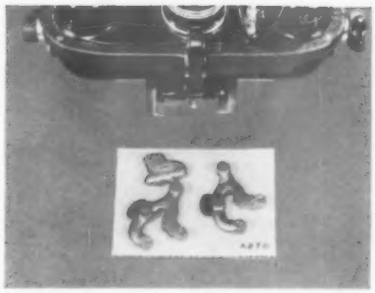
Complete stocks available from factories at White Plains, N. Y. and South Gate, California . . . and from branches at St. Louis, Missouri and Toronto, Canada. On sale at over 1000 distributors here and abroad.

Send for new free Aluminum Manual.

Distributor-Stocked, convenient to buy. Economical to use.
ALL-STATE WELDING ALLOYS CO., INC., White Plains, N. Y.
Call WHite Plains 8-4646 or write for nearest distributor

For details, circle No. 18 on Reader Information Card

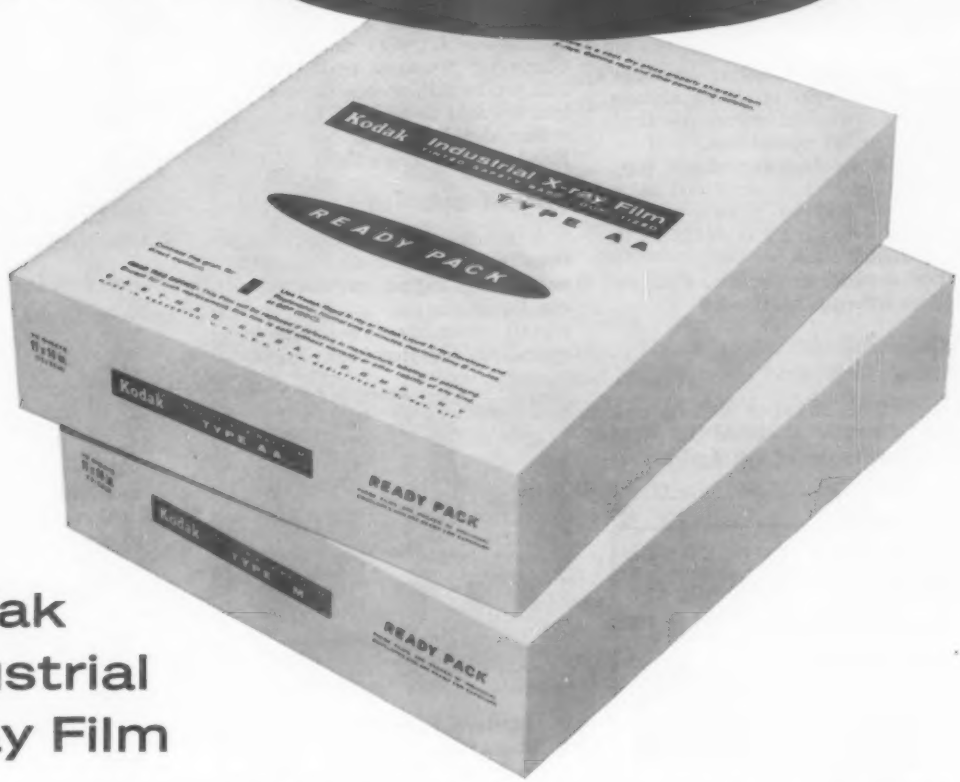
1) No darkroom loading. Ready for exposure as it comes from the box.



2) Just place in position and expose —the film is protected from dust, dirt, light and moisture.

3) In the darkroom, pull the rip strip, remove film, and process.

···NEW!··· READY PACK ····



Kodak Industrial X-ray Film

- Sealed tight until processed—keeps clean
- Very convenient to handle—saves time
- Readily available in Type AA and Type M

Here's new convenience when you are inspecting aluminum or magnesium alloys, thin steels, plastic or anything where lead screens are not required.

Kodak Industrial X-ray Film, Type AA and Type M-Ready Pack comes to you with each sheet sealed in a light-tight envelope ready for exposure. A convenient rip strip makes it easy to open in the darkroom.

These films come 75 to a box in sizes 8 x 10, 10 x 12, 11 x 14, 14 x 17. Order them from your Kodak X-ray dealer.

Kodak
TRADE MARK

EASTMAN KODAK COMPANY
X-ray Division • Rochester 4, N. Y.

For details, circle No. 19 on Reader Information Card

Universal-joint Clamp

By fitting their popular "G" clamp with a drop-forged universal joint, Merrill Brothers, Arctic St., Maspeth, N. Y., extended its usefulness.

Primarily designed for use where unusual side strains are brought to

bear on shackles in rolling drums or tanks while welding, these clamps also have proved to be very practical in many other operations.

Completely drop forged and heat treated, the Merrill Universal Joint Clamp is said to have a safety factor of 5 to 1 and is available in six standard sizes.

For details, circle No. 112 on Reader Information Card.

Portable Roll-spot Welding Machine

A portable roll-spot welding machine specially designed to weld three thicknesses of metal which re-

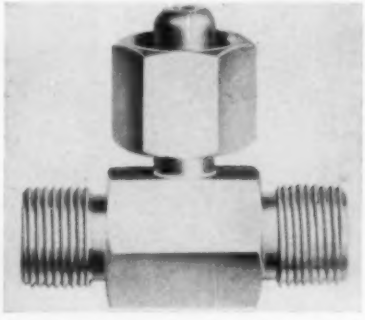
quire high clamping pressure, is now being produced by the newly-consolidated Progressive Welder and Machine Co., 915 Oakland Ave., Pontiac, Mich.

This machine is patterned after the single-drive roll-spot welding machine, but has a synchronized, double-wheel, air motor drive. Clamping pressures up to 1000 lb and production speeds of up to 250 ipm are said to be attainable.

For details, circle No. 113 on Reader Information Card.

Oxygen Coupler Tee

A special brass fitting, oxygen coupler tee No. T-62—permitting use of two oxygen regulators with one liquid oxygen cylinder, or with pigtail assemblies on manifolding cylinders—has just been announced



by Western Enterprises, Inc., Bay Village, Ohio.

According to the manufacturer, the oxygen coupler tee was designed to meet increasing demand for this type of fitting, and is now in stock for immediate delivery.

For details, circle No. 114 on Reader Information Card.

Ultrasonic Soldering Iron

Development of an 8-oz, 10-w ultrasonic soldering iron, capable of soldering a wide range of materials without flux, is announced by the Vibro-Ceramics Division, Gulton Industries, Inc., 212 Durham Ave., Metuchen, N. J.

The ultrasonic iron is designed for soldering semiconductor materials as well as metals such as aluminum, magnesium and their alloys, especially those having very rapid surface oxidation. The new unit completely eliminates surface pretreatment as well as postcleaning to remove flux.

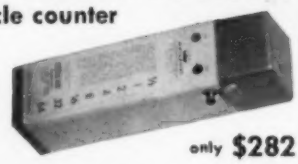
For details, circle No. 115 on Reader Information Card.

Quick-change Die for Resistance Welding

Among the design features employed by National Electric Welding Machines Co., Bay City, Mich., in the manufacture of special resistance welding machines is a new "floating" die used in connection with a nonferrous indexing table. Close tolerance precision is maintained while the quick-change features of the die are said to permit replacement by unskilled labor. According to the manufacturer, considerable time is saved during job changeover on multistation dial-feed machines.

For details, circle No. 116 on Reader Information Card.

Now you can check
WELD TIME with
new PORTA-COUNT
cycle counter



only $282

Counts actual weld time during firing. PORTA-COUNT is light and small enough to carry easily—keep right on the job. Completely portable and self-contained with long life (up to 2 years) batteries. Counts single phase.

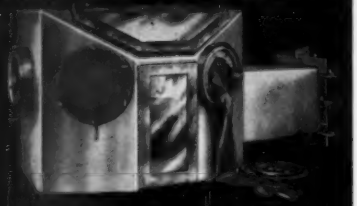
No Plug In No Clips No Clamps

PORTA-COUNT uses an inductive pick up to count, sensing magnetic field around power line, welding buss, transformer or electrodes.

INSTRUMENT CONTROL CO.
1554 Nicollet Avenue
Minneapolis 3, Minnesota

For details, circle No. 20 on Reader Information Card

FOR WORK IN A CONTROLLED ATMOSPHERE



BLICKMAN
VACUUM DRY BOX

Designs and specifications are available for a variety of welding enclosures for research and production welding, and for work in the fields of metallurgy and physical chemistry. These enclosures can be fully evacuated and then be filled with an inert gas for welding in an inert atmosphere. Write for Technical Bulletins on various types of welding enclosures: S. Blickman, Inc., 3008 Gregory Avenue, Weehawken, N. J.

BLICKMAN
LABORATORY EQUIPMENT

Look for this symbol of quality Blickman-Built

For details, circle No. 21 on Reader Information Card

Modern welding processes like these demand a modern power supply!

Glenn Constant Voltage Power Supply with Stepless Vernier Slope Control

*** TIG** (Tungsten Inert Gas) *** MIG** (Metallic Inert Gas)
*** Short Arc * Submerged Arc**
*** Magnetic Flux**

Never underestimate the importance of the power supply to the proper operation of today's improved welding processes.

Weld quality, appearance, speed and economy all depend on matching arc characteristics to the requirements of the process and the material. If your power supply can't produce the required characteristics, you're sure to lose some or all of the performance you want.

Glenn Pacific, working closely with major welding process development engineers, has kept pace with process requirements. For example, GLENN constant voltage power supplies with linear slope control have solved major problems in MIG and Short Arc welding on aluminum and ferrous alloys, and many exotic "space age" metals.

Get the facts *now* about GLENN Power Supplies matched to your welding needs—you'll be hours and dollars ahead! For details, please address Dept. 138.

GLENN PACIFIC
POWER SUPPLY CORPORATION

703-37th Avenue • Oakland 1, California
Originators of CV Power Supplies

Eastern Office
221 Dukes Rd., Rahway, N. J.

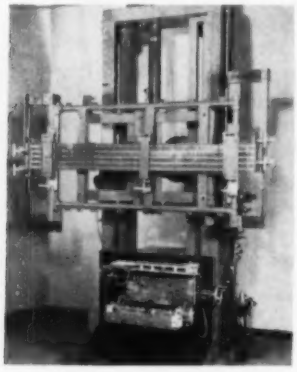
Midwestern Office
640 So. York, Elmhurst, Ill.

* GLENN Balanced Wave Power Supply for TIG Welding * GLENN Manual and Stud Welder Power Supply * GLENN Arc Gouger Power Supply * GLENN Constant Potential Welder for "Gang" Manual Welding * GLENN Industrial Power Supplies and Heavy Duty Variable Voltage Transformers

For details, circle No. 22 on Reader Information Card

Mechanized Brazing Fixture

A large fixture for the semi-automatic brazing of aluminum-finned copper tubes to steel headers was designed and built by Induction Heating Corp., 181 Wythe Ave., Brooklyn 11, N. Y. With the aid of silver-solder preforms, the equip-



ment is described as not only solving the problem of costly service failures but cutting production time by 75% as well. Operation of the machine requires little skill.

For details, circle No. 117 on Reader Information Card.

Tee Connection

A multipurpose, tee connection for portable extendable manifolds, is offered by The Bastian-Blessing Co., 4201 W. Peterson Ave., Chicago 46, Ill. The 13000 Series Tee Connections are said to provide

a low-cost method of manifolding cylinders for portable or temporary use, and may also be used to connect two regulators to a single cylinder.

The tees are available with any popular CGA end connection, and with connecting pigtails. Fuel gas models are available with or without built-in flash arresters and pigtails.

For details, circle No. 118 on Reader Information Card.

A-C Arc-welding Machine

Simplified controls are one feature of a new M&T Murex a-c arc-welding machine offered by Metal & Thermit Corp., Rahway, N. J.

Built to NEMA standards, the machine has 66 heat settings, over a range of 7 to 300 amp, with built-in voltage control for deep penetration or for soft-arc welding of light gages.

For details, circle No. 119 on Reader Information Card.

Brazing Furnace

Results from tests with a new "cold-wall" brazing furnace, announced at the Wichita, Kan., Division of Boeing Airplane Co., show a high degree of flexibility and extremely rapid heating and cooling cycles.

Main features of the cold-wall unit include placing the heating element next to the structure being brazed, the addition of a cooling system and elimination of costly metal envelopes for each part. The new furnace gets its name from the fact that its walls remain relatively cool during the brazing operation because of relocation of the heat source.

For details, circle No. 120 on Reader Information Card.

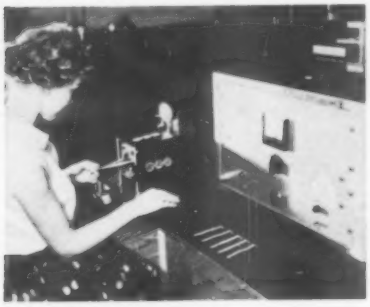
HIGHEST YIELD
They mean National Carbide's calcium carbide —gets ten tests!
Always nearby— in the BIG RED DRUM. Wire for supplier...
NATIONAL CARBIDE COMPANY
A DIVISION OF AIR REDUCTION COMPANY, INC.
150 East 42nd Street, New York 17, N.Y.

For details, circle No. 23 on Reader Information Card

Ultrasonic Spot-welding Unit

An ultrasonic spot-welding machine especially suited to joining parts in semiconductors, printed circuit boards and foil-wound transformers and capacitors is offered by International Ultrasonics, Inc., 1697 Elizabeth Ave., Rahway, N. J.

The instrument is described as having a new high-temperature



high-efficiency transducer and a unique self-tuning circuit. The combined features are said to double welding capacity and to minimize need for operator skill. Frequency is automatically adjusted to optimum for materials and thicknesses joined. Thickness range for top piece is given as 0.00025 to 0.006 in.; no limit in bottom piece.

For details, circle No. 122 on Reader Information Card.

Wire-solder Dispenser

A simple palm-fitting tool, the Kormat is a dispenser for feeding wire solder from 0.028 to 0.074 in. in diam. A thumb push-button feeder provides just the amount of solder desired while a variety of straight or curved probes offers versatility.

According to the manufacturer, Products For Industry, 220 S. Rose St., Los Angeles, Calif., a typical load of 20 ft of 60/40 rosin-core wire, 0.050 in. diam, is reloaded in seconds.

For details, circle No. 121 on Reader Information Card.

Soldering Kit

A kit of paste solder materials for the appliance, electric and electronic industries is offered by Fusion Enginering Co., 17921 Roseland Ave., Cleveland 12, Ohio.

Purpose of the kit is to allow production engineers to evaluate the paste solder materials under actual production conditions to determine cost savings and increased production potential.

For details, circle No. 124 on Reader Information Card.

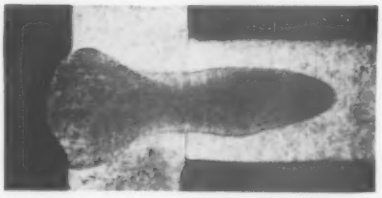
Light-gage T-1 Steel

Light gages of USS T-1 steel will become commercially available later this year according to a recent report from the U. S. Steel Corp., 525 William Penn Place, Pittsburgh 30, Pa. The new sheet sizes of the higher-strength low-alloy steel are expected to be of great interest to designers of a wide range of industrial products as well as transportation and military equipment.

The thin sections were developed especially for the Army's missile program because forming and welding can be readily accomplished without loss of strength, it is said. The added advantage of large savings in weight was recently demonstrated at Ft. Benning, Ga., where an erector-launcher made of light gage T-1 was estimated to weigh 30% less than it would if made from standard structural steel.

For details, circle No. 123 on Reader Information Card.

Who said: "Un-weldable?"



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For details, circle No. 24 on Reader Information Card

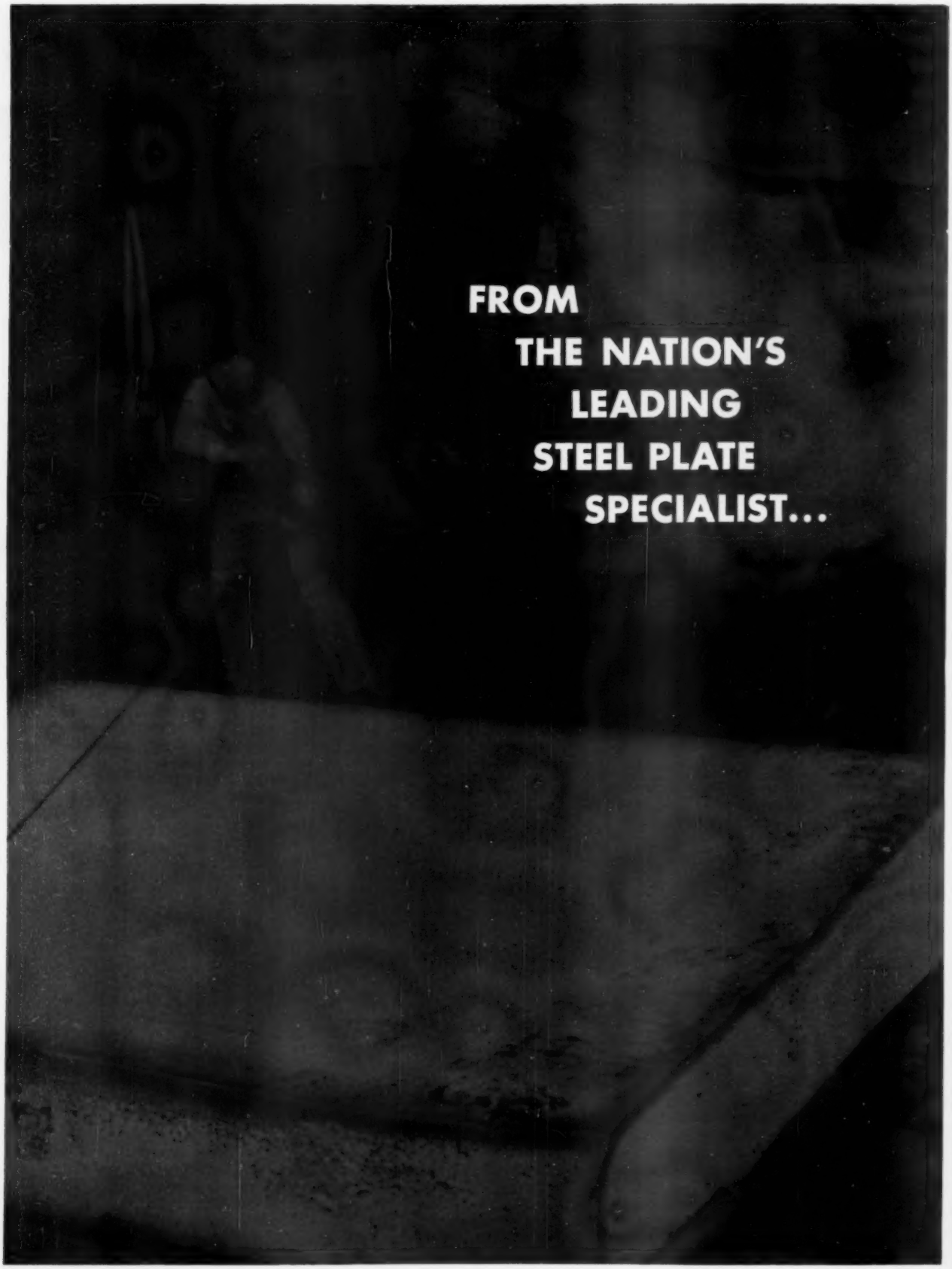
Precision Spot-welding Head

A special ball-bearing construction is reported to impart a precise vertical-linear motion to the upper electrode of a spot-welding head offered by Weldmatic Division of Unitek Corp., 950 Royal Oak Dr., Monrovia, Calif. This character-

istic is said to eliminate electrode wiping action as preset pressure is applied to critically fine joints.

Provision is made for interchangeable electrodes of various configurations and capacitor-discharge power for the Model 1037 is obtained from any such supply made by the same company.

For details, circle No. 144 on Reader Information Card.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LUKENS PLATE MATE

For details, circle No. 26 on Reader Information Card

Dot Welding

Scratches, cavities and undercuts in manufacturing production dies need no longer be a problem in the metal industry. A fast and inexpensive method of repairing the dies has been developed recently by the Mid States Welder Manufacturing Company 6025 S. Ashland Ave.,

Chicago 36, Ill. Reportedly field tested for five years, the process is called "Dot Welding" and described as a fusion of metal pellets by a gun type welding device into the damaged die which need not even be removed from the machine.

For details, circle No. 125 on Reader Information Card.

Lightweight X-ray Unit

A portable X-ray unit described as having a power rating of 300-KVP-3MA, a penetration capability of 4-in. steel and a weight of 150 lb was announced by Balteau Electric Corp., Stamford, Conn.

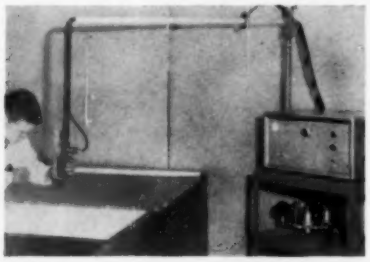
The engineering achievement of the unusual weight-power-penetration combination of the Baltograph

300 is said to permit accurate radiography under the widest variety of operating conditions, in the plant and in the field, on thin-walled parts to heavy sections. Carrying cases are provided for the X-ray head and the 41-lb control panel.

For details, circle No. 126 on Reader Information Card.

Honeycomb Splice Welding

Hexcel Products, Inc., 2332 Fourth St., Berkeley, Calif., has developed a splice-welding unit which was designed for high-speed precision splicing of structurally critical hon-



eycomb core materials. It is reported to average 12 to 15 welds per second by automatically repeating the preset cycle.

For details, circle No. 127 on Reader Information Card.

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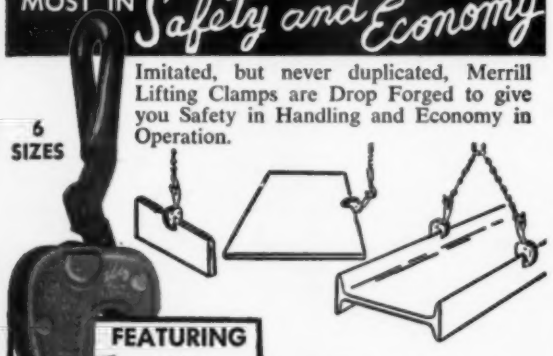

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Authors . . .

please note!

All authors interested in presenting papers at the AWS 42nd Annual Meeting to be held in New York City on April 17–21, 1961 are advised of a change in preliminary arrangements.

The usual forms, "An Invitation to Authors" and "Author's Application Form," were printed as a detachable insert in the May issue of the Welding Journal instead of being sent through the mails.

Additional copies of the forms may be obtained by writing to AWS Headquarters, 33 West 39th St., New York 18, New York.

CLEARING HOUSE—

Torch Firm Sets a Scorching Pace

By JACK CLEARY

HARRIS CALORIFIC CO., Cleveland pioneer 57 years ago in manufacture of torches and allied equipment for the oxyacetylene metal cutting and welding industry, is fully living up to the second part of its name these days.

JACK CLEARY

The word calorific, according to Webster, means hot. And Harris Calorific certainly is making hot with its sales figures.

Clarence M. Taylor, president, reveals that the company's world-wide net sales for this year's first quarter set a new record . . . . . a 42% gain over the like 1959 period.

This comes on top of a 41.5% sales gain for the full year 1959.

For domestic sales alone, the sales increase last year amounted to a husky 52%.

The late John Harris, the firm's founder and first president, accidentally discovered the principle of oxygen flame cutting of metal while experimenting with synthetic rubies shortly after the turn of the century. However, Harris Calorific has remained relatively small in an industry which now includes several giants.

High Rate of Growth

But the current growth—more than a 40% rate—is well ahead of the industry's average of 17% for last year.

This is attributed to development of newly designed equipment for faster and more economical metal flame cutting and to expansion of the company's distribution network.

Le[illegible] P[illegible]ins, [illegible]
de[illegible]

HARRIS' SALES GAIN 42% IN FIRST QUARTER

...and May 1960 was the biggest month in its 57-year history....

There are a lot of good reasons for this 1960 vs. 1959 performance

More and more users of welding and cutting apparatus are turning to Harris. As a prime source for the new and the practical in this field, Harris strives to think like its customers, and develop what they require for efficient, low cost operations.

Leadership has resulted from such newly designed apparatus as the industry's first gaugeless regulator; the first automatic welding torch; the first multi-stage regulator; the first oxypropane cutting torch; the first efficient oxy-natural gas cutting torch; Cut-o-mation; as well as a host of other progressive contributions.

More new Harris developments are coming out of an aggressive, continuing research program, which will be of benefit to industry all over the world.

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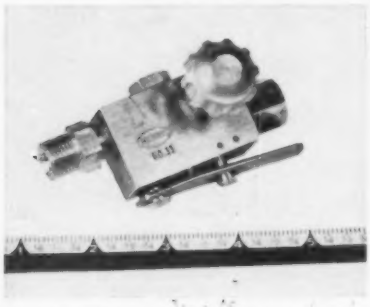
THE HARRIS CALORIFIC COMPANY, 5501 CASS AVENUE, CLEVELAND 2, OHIO

For details, circle No. 28 on Reader Information Card

Oxygen Saver

The Harris Calorific Co., 5501 Cass Ave., Cleveland 2, Ohio, has introduced the Oxygen-Saver for flame cutting equipment.

The No. 33 duo-control Oxygen-Saver is for single-torch cutting machine operation and is said to



permit the use of high heat flame for instant starts. When actuating the preheat oxygen-control lever, the flame needed to support continuing cutting action is reduced to a minimum. A 70% reduction in the amount of preheat gases is claimed, in addition to an improved cut.

For details, circle No. 128 on Reader Information Card.

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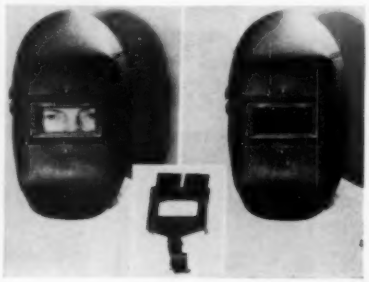
Welder's Helmet

A welder's helmet is available which eliminates lifting of the helmet from the face when the welder inspects his work. The helmet is designed so that the protec-



tive eyeguard lifts from view with the workman's jaw motion. This leaves a clear plastic area for viewing. The helmet, of standard fiber construction, is adjustable. Manufacturer is Auto-View Welding Helmet Co., Central Tower Building, 1424—4th St., Suite 510, P.O. Box 917, Santa Monica, Calif.

For details, circle No. 129 on Reader Information Card.

Welding Machine

Featuring the exclusive Gold Star rectifier, and powered by a Kohler 25-hp, 2-cylinder, air-cooled gasoline engine, the new Miller AD-225-L is claimed by Miller Electric Mfg. Co., Inc., Appleton, Wis., to perform all these functions in a notably superior and economical manner: a-c welding; d-c welding; metallic inert-gas welding; generates 7 kw of

115/230 v a-c power; supplies 1 kw of auxiliary 115 v d-c power while welding; warms viscous fluids for pumping and thaws frozen pipes; battery charging and battery boosting.

This model delivers 300 amp at 30 v a-c or 225 amp at 30 v d-c welding power at 100% duty cycle. Open circuits of 75 v ac and 65 v dc assure fine results with a-c, d-c or ac-dc electrodes.

A complete range of accessories and optional equipment is available, including a high-frequency unit for tungsten inert-gas welding, road trailers, remote controls, etc.

For details, circle No. 130 on Reader Information Card.

Automated Welding Machine

An automated welding machine made by Precision Welder and Flexopress Corp., 3520 Ibsen Ave., Cincinnati 9, Ohio, is said to assemble and weld 1850 transistor cases an hour. This is a many-fold increase

in efficiency over former production methods, according to the manufacturer.

Mounted atop a 5-ft square table, and centered about a variable speed indexing turntable, are six manufacturing stations.

For details, circle No. 131 on Reader Information Card.

Seamless Pipe Fittings

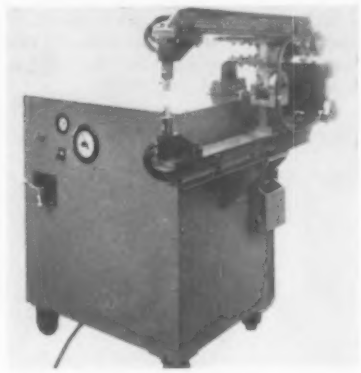
Midwest Piping Co., Inc., 1450 S. Second St., St. Louis 4, Mo., has announced a line of seamless carbon-steel welding fittings in sizes ranging through 24 in. and to toler-

ances above ASA standards. This line is in addition to the standard and special welded type fittings, offered in sizes through 48 in. of all weldable metals.

For details, circle No. 132 on Reader Information Card.

Diode Resistance Machine

A three-phase balanced-demand direct-energy resistance welding machine which utilizes the new silicon power diodes, is the first silicon-rectifier resistance welder in actual operation, according to Helfrecht Machine Co., 414 So. Hamilton St., Saginaw, Mich. The unit operates



as a standard rocker arm for welding of aluminum or steel. With additions of a suspension hook and water cooled cables, the welding gun can operate in portable fashion utilizing the same power supply. Silicon diodes make this feature possible by virtue of their high-peak inverse voltage rating.

For details, circle No. 133 on Reader Information Card.

Metal-arc Spot-welding Unit

An inert-gas metal-arc spot-welding unit has been added to their line of welding equipment by Hobart Brothers Co., Troy, Ohio.

The unit is described as having a completely automatic welding cycle controlled by a timer panel. Mild steel, galvanized carbon steel, stain-

less, aluminum and other metals, 0.30 to 0.250 in. thick, can be spot welded from one side. Different types of welds, such as tack welds, are said to be possible and rates of over 20 spots per minute, using any shielding gas, can be attained depending on the application.

For details, circle No. 134 on Reader Information Card.

Lightweight Cutting Torch

A lightweight cutting torch, featuring a built-in pressure control system for smooth, even cutting with various types of fuel gases, has been announced by Weldit, Inc., 990 Oakman Blvd., Detroit 38, Mich.

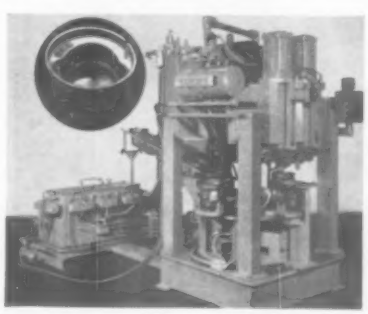
Designed to eliminate flashbacks, "Jet-stream 707," is equipped with an injection-type mixing chamber and valve system which provide a controlled, steady application of oxygen and prevent "jumps." According to the company, the new torch cuts steel up to 15-in. thick or more and works equally well with all types of fuel gases.

For details, circle No. 135 on Reader Information Card.

High-speed Stud-welding Unit

Progressive Welder and Machine Co., 915 Oakland Ave., Pontiac, Mich., has developed a special automatic high-speed stud-welding machine which is said to cut costs by enabling simple machine screw products to be used as studs. Eliminated is the need for a flange, a projection or a flux farrel. Progressive's new unit is a four-station index machine.

For details, circle No. 136 on Reader Information Card.



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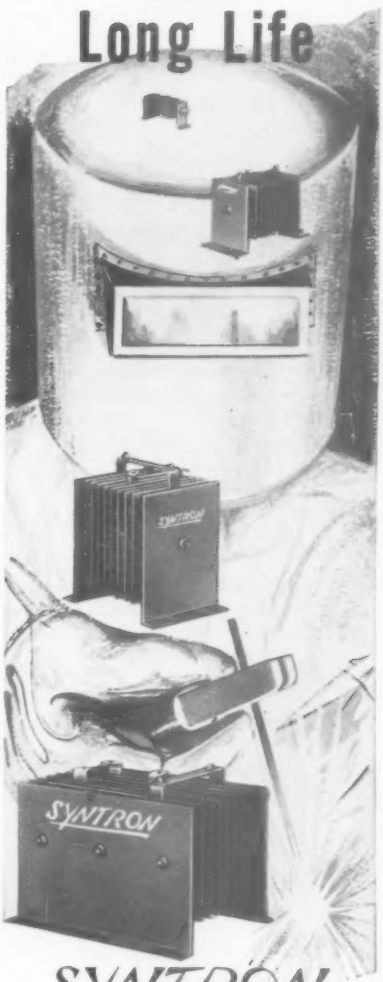

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For details, circle No. 30 on Reader Information Card

Portable A-C Welding Outfits

A line of medium-duty all-purpose a-c portable welding outfits is offered by Metal and Thermit Corp., Rahway, N. J. The units are said to operate from a 230 v source and

provide from 15 to 180 amp welding current. Electrode capacity is $^{1}/_{16}$- through $^{3}/_{16}$-in. diam. Included are all accessories needed for welding, even to a welding hood.

For details, circle No. 138 on Reader Information Card.

Weld-cleaning Hammer

A weld cleaning hammer called the Atlas Tomahawk, made by press fitting and pinning the head to the shaft, is offered by Atlas Welding

Accessories, Inc., 707 E. Lewiston, Ferndale 20, Mich.

The head is said to be positively secured against flying off.

For details, circle No. 137 on Reader Information Card.

Welding and Cutting Outfits

Two welding and cutting outfits have been announced by Modern Engineering Co., 3401–15 Pine Blvd., St. Louis, Mo.

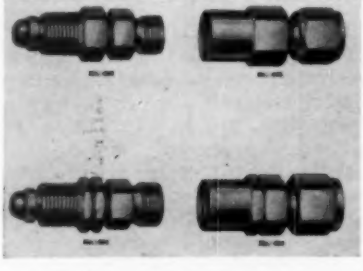
Outfit shown includes Meco's Weldmaster torch and cutting attachment with 3 welding tips, one cutting tip, multiseat regulators, goggles, torch wrench, flint lighter, $12^{1}/_{2}$ ft of $^{3}/_{16}$-in. Tu-line hose and Meco 40-page instruction manual. Welding and cutting ranges: $^{1}/_{2}$-in. and 3-in. steel, respectively.

The other outfit has a welding range up to $^{5}/_{16}$-in. and cutting range up to $1^{1}/_{4}$-in. steel.

For details, circle No. 139 on Reader Information Card.

Hose and Machine Adaptors

Now available are four inert-arc, air–water hose and machine adaptors—especially designed to adapt new IAA standard fittings to old-style torches or machines.



According to the manufacturer, Western Enterprises, Inc., P.O. Box 57, Bay Village, Ohio, the new fittings are two-piece, silver-soldered units that feature swivel nuts to assure positive, gastight seating.

For details, circle No. 140 on Reader Information Card.

Resistance-welding Switch

A lightweight hand switch that can be used for stationary or portable welding machines is available from A. P. Seedorff & Co., Inc., 4617 E. Cecelia St., Bell, Calif.

Developed for the aircraft industry, the switch has one- or two-stage initiating buttons for high or low weld-heat selection as well as a selflocking button for electrode retraction.

For details, circle No. 141 on Reader Information Card.

Pressure Regulators

Two pressure regulators have been announced by Watts Regulator Co., Embankment Rd., Lawrence, Mass.

Model 6 is constructed of UL approved materials for LP gas

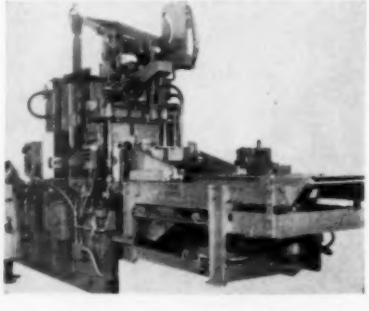
and No. 7 of UL materials for acetylene gas.

Constructed of die-cast zinc with internal parts of brass and diaphragm and disk of oil-resistant buna-N, both are available in $^{1}/_{4}$-in. size only. They may be used as 2-, 3-, or 4-way regulators.

For details, circle No. 142 on Reader Information Card.

Automatic Strip Welding

A heavy-duty automated welding machine welds the ends of 20- x 0.377-in. flat skelp coils to make a single strip for a continuous tube



mill. Manufactured by The Taylor Winfield Corp., Warren, Ohio, the unit automatically aligns the ends, clamps and flash welds and then removes the excess flash.

For details, circle No. 143 on Reader Information Card.

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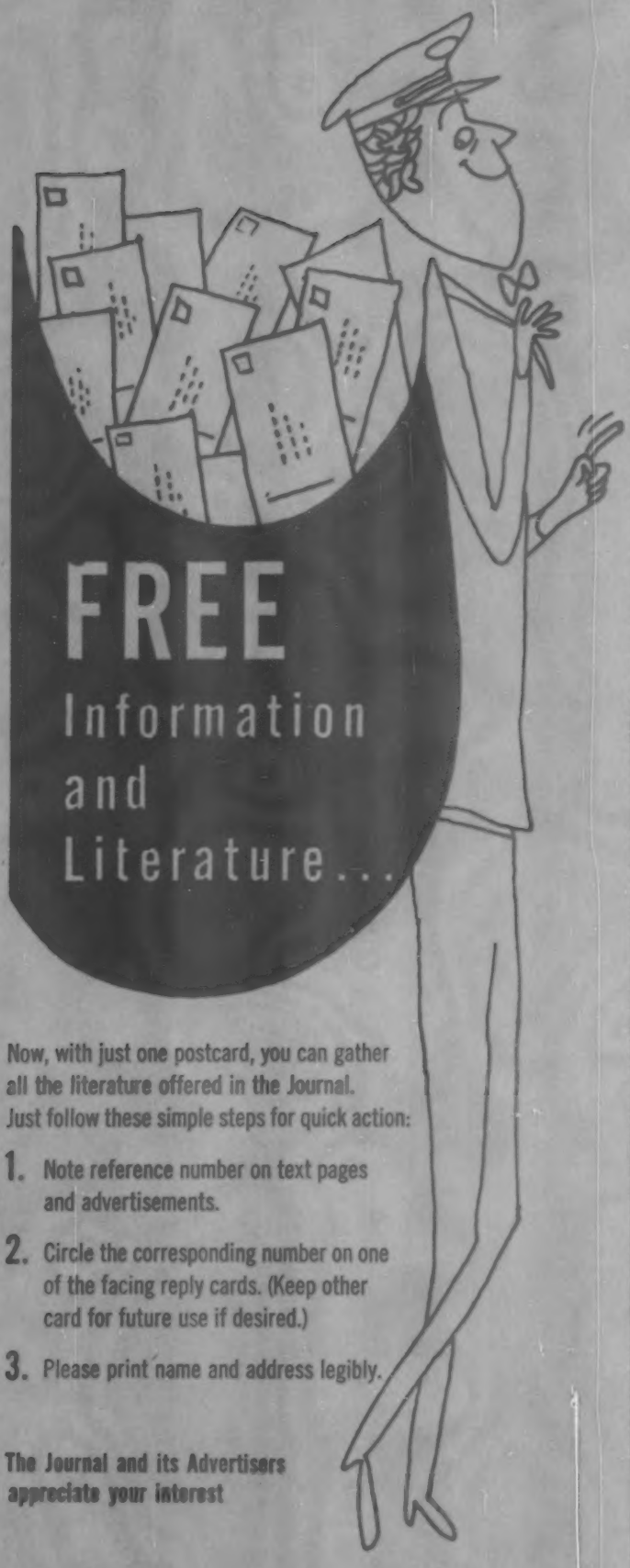

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WRC

SUPPLEMENT TO THE WELDING JOURNAL, AUGUST 1960

Effect of Steel Backup Blocks on Series-Spot Welding

Effect of substituting steel, a low-conductivity material, for copper and its alloys as a backup material is determined through WRC sponsored investigation

BY E. F. NIPPES, W. F. SAVAGE AND K. C. WU

ABSTRACT. The tensile-shear strength of welds and the distribution of shunting currents among the top sheet, the bottom sheet and the backup block were determined for a variety of conditions in the series-spot welding of 0.036-in. auto-body steel. In all cases, RWMA Class 2, 2-in. continuous-radius electrodes were used, and a secondary welding current of 12,400 amp was utilized.

The weld strength and the sum of the shunting currents in the bottom sheet and the backup block, termed the "useful shunting current," were essentially the same for copper, steel and RWMA Class 5 backup blocks (IACS conductivities of 100, 18 and 11.5%, respectively). Increasing the weld spacing from 2 to 6 in. increased the useful shunting current by about 5 to 8% and resulted in increased weld strength. Decreasing the electrode force from 700 to 480 lb caused a slight decrease in useful shunting current, but resulted in an increase in weld strength. Although the useful shunting currents with degreased-and-pickled stock averaged nearly 10% higher than those measured with as-received stock, the strengths of welds prepared from material with these two surface conditions were essentially the same. The tensile-shear strength of welds made with a steel backup block and RWMA Class 3 stools (IACS cond. 52%) was consistently higher than the strength of welds made with a steel backup block and copper stools (IACS cond. 100%), even though the useful shunting currents were almost the same.

Secondary voltages must be increased by approximately 10% to obtain the same secondary weld current and weld strength when steel backup blocks are substituted for copper or RWMA Class 5 backup blocks.

E. F. NIPPES, W. F. SAVAGE and K. C. WU are associated with the Rensselaer Polytechnic Institute, Troy, N. Y.

Introduction

The series-spot welding process has been used widely for the fabrication of mild-steel sheet in the automotive industry. Not only are increased production rates realized with this process, but, in addition, indentation and marking on one side of the weldment may be minimized. However, an inherent disadvantage of series-spot welding arises from the fact that the shunting current in the top sheet does not contribute to the welding operation, and hence reduces the electrical efficiency of the process. The existence of this shunting current in the top sheet results in increased current density in the electrodes, and thus tends to reduce electrode life.

The effect of such variables as electrode spacing, electrode geometry, stock preparation, stool material, backup block material and electrode force on shunting current was studied in previous investigations[1-4] at RPI.

Previous work demonstrated that the shunting current in the top sheet was not reduced by employing copper in place of a lower-conducting copper alloy as a backup block.[4] In fact, the use of a high-conductivity material, such as copper, for backup blocks rendered the weld strength more sensitive to spot spacing. Thus it appeared desirable to investigate the use of backup blocks constructed of an alloy with electrical resistivity comparable to that of the stock being welded.

It was decided therefore to study the effect of substituting steel, an inexpensive, low-conductivity material for copper and its alloys as a backup material.

Object

The object of this investigation was to study the effect of a steel backup block on the shunting current and tensile-shear strength of spot-welded joints in 0.036-in. auto-body stock, and to compare the results with those obtained using copper and RWMA Class 5 backup blocks.

Material

The material used in this investigation was 0.036-in. cold-rolled, low-carbon, open-hearth, commercial-quality auto-body steel. The chemical analysis and mechanical properties of the steel have been reported in a previous report.[3] All material was supplied in the pickled-and-lightly-oiled condition.

Material Preparations. The welding characteristics of 0.036-in. auto-body stock were investigated in both the as-received and the degreased-and-pickled condition.

The as-received steel had a surface-contact resistance ranging from 700 to 1500 microhms, whereas the degreased-and-pickled stock had a contact resistance of 20 microhms or lower. Degreased-and-pickled specimens were prepared by degreasing in acetone, pickling in a 50% HCl solution for 10–20 sec, water rinsing, dipping in acetone and wiping dry immediately.

Figure 1 shows the essential details of the weld specimens employed. The 0.036-in. auto-body steel was sheared to the appropriate over-all dimensions, the 1- x 2-in. notch was punched in one side of each specimen, and a U-shaped bend formed in the center as shown. By overlapping two standard specimens as shown in Fig. 1, clearance was provided for inserting the U-shaped toroids employed in the measurement of shunting currents in the top and bottom sheets (refer, also, to Fig. 2). These forming operations were carried out on the material in the as-received, pickled-and-oiled condition. When required, degreasing and pickling operations were performed after forming.

Equipment

Welding Equipment

The series-spot welding equipment, assembled during earlier investigations, is described in a previous report.[1]

RWMA Class 2, 2-in. continuous-radius electrodes were used in conjunction with backup blocks with removable stools, and one side of the secondary winding was connected to each electrode. Three materials were utilized for the backup blocks:

1. Copper (100% IACS conductivity)
2. RWMA Class 5 material (11.5% IACS conductivity)
3. AISI 1015 Steel (18% IACS conductivity).

Two materials were investigated for the stools:

1. Copper (100% IACS conductivity)
2. RWMA Class 3 material (52% IACS conductivity).

The welding-current magnitude was adjusted by changing the primary welding voltage over the range from 250 to 550 v. The weld time was controlled by a synchronous electronic weld timer, and the welding current flow was adjusted to provide a current waveform as nearly sinusoidal as possible (100% heat).

Instrumentation and Equipment for Measuring Shunting Current

The shunting currents in the top sheet, bottom sheet and backup block, and the total current were measured simultaneously with four air-core toroids. Two 1-in. diam ring-shaped forms were fabricated from $^1/_8$- × $^1/_2$-in. lucite sheet. One ring toroid, used for measuring the total current, was wound with #20 insulated wire, and the other, used for measuring the current in the backup block path, was wound with #26 insulated wire. Two U-shaped air-core toroids were used to measure the shunting currents in the top and bottom sheets. The core of these toroids consisted of two pieces of $^1/_8$-in. thick, $^1/_2$-in. wide, 6-in. long lucite strips which were wound with two layers of #26

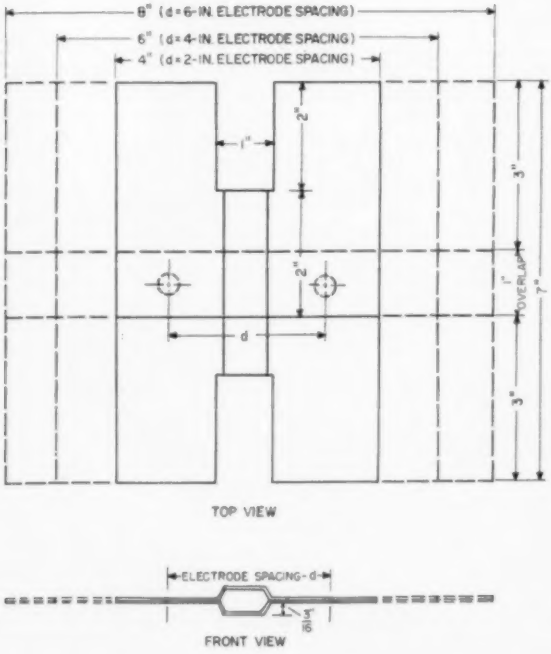

Fig. 1—Details of special weld specimens employed in this investigation

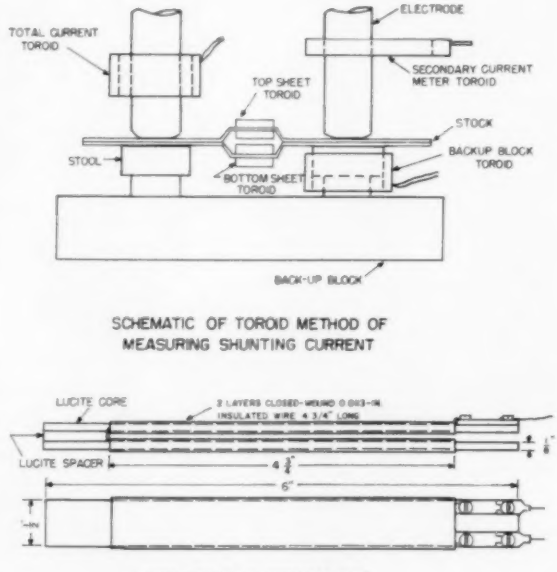

Fig. 2—Schematic of toroid method of measuring shunting current and constructional details of U-shaped toroids

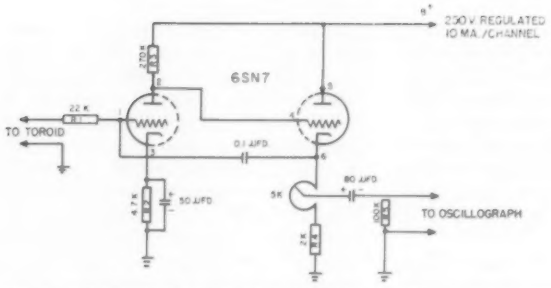

Fig. 3—Schematic diagram of integrating amplifier (single channel)

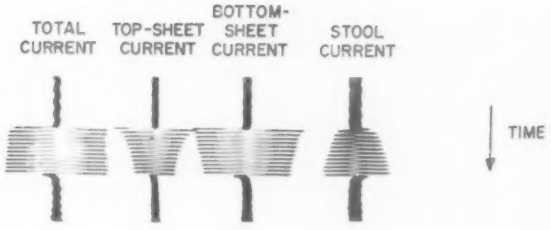

Fig. 4—Sketch of oscillogram of shunting currents for 12-cycle weld in as-received stock with 12,400-amp secondary current

insulated wire and cemented to a lucite spacer. Constructional details of the U-shaped toroid, and a sketch of the arrangement of the four current measuring toroids are shown in Fig. 2.

Signals from the toroids were integrated and amplified in a specially constructed multichannel integrating amplifier, the output of which was recorded using a multi-element galvanometer-type recording oscillograph.

A schematic diagram of a typical integrator and amplifier is shown in Fig. 3.

The welding current was measured in the secondary circuit with a direct-reading secondary current meter[3] which has an accuracy of ±3% of full-scale reading. The air-core toroid of this meter was placed in a fixed position around one electrode, as shown in Fig. 2.

The toroid circuits were calibrated with the direct-reading secondary current meter by use of a copper sheet which was insulated from the backup stools. The ring-shaped toroids were placed around the electrodes and two U-shaped toroids were placed around the copper sheet. Thus, during calibration, the same magnitude of current was measured by all of the toroids. Calibration was made at numerous current values in the range from 3000 to 13,000 amp by adjusting the primary voltage.

The backup block had the same design as that used in the previous investigation.[4]

Procedure

In this investigation of the effect of a steel backup block, the same combinations of welding conditions were employed as in the previous investigation,[4] specifically:

Welding time . . . . . 12 cycles
Welding current . 12,400 ± 600 amp
Electrode force . . . . . 480 and 700 lb
Electrode spacing . . . . 2, 4 and 6 in.
Surface condition . . . . . As-received, degreased-and-pickled
Stool material . . Copper and RWMA Class 3
Electrode material . . RWMA Class 2

For comparison of the effect of backup block material, a Class 5 backup block with a conductivity of 11.5% of copper and a forged copper backup block with a conductivity of nearly 100% based on IACS were also used. Two U-shaped sheets were overlapped 1 in. and welded as shown previously in Fig. 1. Two standard 1-in. wide by 7-in. long tensile-shear specimens were then sheared from each weld specimen, one for each weld nugget.

The total secondary current, and the shunting currents in the backup bar, the top sheet and the bottom sheet were recorded simultaneously with the multi-element galvanometer-type oscillograph. A typical oscillographic record is shown in Fig. 4. The shunting current in amperes was obtained from the average of the first three cycles since the welding action was essentially complete by the end of the third cycle.

Discussion of Results

The results of this investigation have been summarized in graphical form in Figs. 5, 6, 7 and 8. A further summary of the experimental results has been included in Table 1.

Effect of Stool Conductivity with Steel Backup Block

Figure 5 illustrates the effect of stool conductivity on the shunting currents and tensile-shear strength for 2-, 4- and 6-in. weld spacings with an electrode force of 700 lb and a steel backup block. Figure 6 presents the same information for an electrode force of 480 lb.

Examination of Fig. 5 reveals that the shunting currents are not significantly influenced by the conductivity of the stools at any of the weld spacings studied. The shunting currents measured with as-received and with degreased-and-pickled stock were the same at all weld spacings within the experimental error for both copper stools (100% IACS conductivity) and RWMA Class 3 stools (52% IACS conductivity). However, consistently higher weld strengths were observed with the same total welding current when the lower-conductivity RWMA Class 3 stools were employed. As may be seen by inspection of Fig. 5, the strengths averaged approximately 150 lb higher with as-received stock and 100 lb higher with degreased-and-pickled stock when RWMA Class 3 stools were used. This increase in weld strength is no doubt a result of the lower heat losses from the weld area due to the lower thermal conductivity of RWMA Class 3 material as compared with copper.

Inspection of Fig. 6, which summarizes the effect of stool conductivity with an electrode force of 480 lb, reveals similar behavior at the lower electrode force. Again, the lower-conductivity stools provide higher weld strength without materially altering the relative magnitude of the shunting currents.

Effect of Electrode Force with Steel Backup Blocks

Comparison of the weld strengths shown in Figs. 5 and 6 reveals that consistently higher strengths were obtained with an electrode force of 480 lb (Fig. 6) than with 700 lb (Fig. 5). This behavior is to be expected, however, since the initial contact resistance is significantly increased by reducing the electrode force.

Effect of Backup Block Material

Figures 7 and 8 summarize the effect of backup block material at three different weld spacings both for as-received and for degreased-and-pickled stock. Figure 7 permits comparison of steel with both copper and RWMA Class 5 as ma-

Table 1—Percent of Total Current in Bottom Sheet Plus Backup Block and Tensile-shear Strength at Different Welding Conditions

Backup block material (stool material)	Electrode force, lb.	As-received						Degreased-and-pickled					
		700			480			700			480		
	Electrode spacing, in.	2	4	6	2	4	6	2	4	6	2	4	6
Steel (Cu Stools)	Useful shunting current (% of total current)	61.5	68.0	71.5	59.5	68.0	70.5	71.5	76.4	81.0	68.5	75.0	79.5
	Tensile-shear strength, (lb)	915	1000	1020	1110	1115	1130	980	1000	1030	1050	1100	1120
Steel (Class 3 Stools)	Useful shunting current (% of total current)	63.0	69.0	72.0	62.0	66.5	71.0	74.5	78.5	79.5	72.5	75.0	75.5
	Tensile-shear strength (lb)	1060	1140	1150	1150	1195	1200	1060	1110	1140	1155	1220	1250
Copper (Class 3 Stools)	Useful shunting current (% of total current)	63.5	70.2	73.0	62.0	69.1	70.5	76.0	80.0	81.5	71.0	76.0	80.5
	Tensile-shear strength (lb)	1120	1190	1220	1220	1210	1280	1120	1180	1230	1250	1270	1300
Class 5 (Class 3 Stools)	Useful shunting current (% of total current)	65.5	69.0	74.0	62.5	68.5	71.5	74.0	78.2	80.5	70.0	75.5	78.0
	Tensile-shear strength (lb)	1120	1170	1230	1230	1250	1290	1140	1220	1190	1200	1240	1280

terials for the backup block for an electrode force of 700 lb with RWMA Class 3 stools. As may be seen by inspection of Fig. 7, the distribution of shunting currents is not significantly influenced by the conductivity of the backup block in either the as-received or the pickled stock for weld spacings from 2 to 6 in.

The tensile-shear strength values observed with copper and RWMA Class 5 backup blocks are essentially the same for a particular weld spacing. At all weld spacings, the strength of the welds made with a steel backup block fall slightly below the values observed with either copper or RWMA Class 5. This results primarily from the fact that the maximum available secondary voltage was barely sufficient to achieve a welding current of 12,400 amp with a steel backup block. As a result, the measured values of current for welds made with a steel backup block usually fell near the low end of the 12,400 ± 600 amp range, and the slightly lower strengths are not surprising. However, utilization of a transformer with a higher secondary-voltage rating would have permitted achieving higher secondary currents and would undoubtedly have provided weld strengths with the steel backup

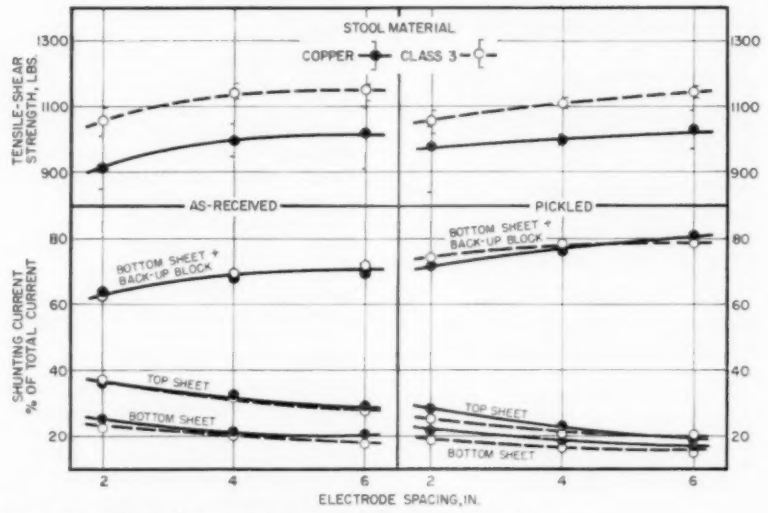

Fig. 5—The effect of stool material on strength and shunting currents, steel backup block, electrode force 700 lb.

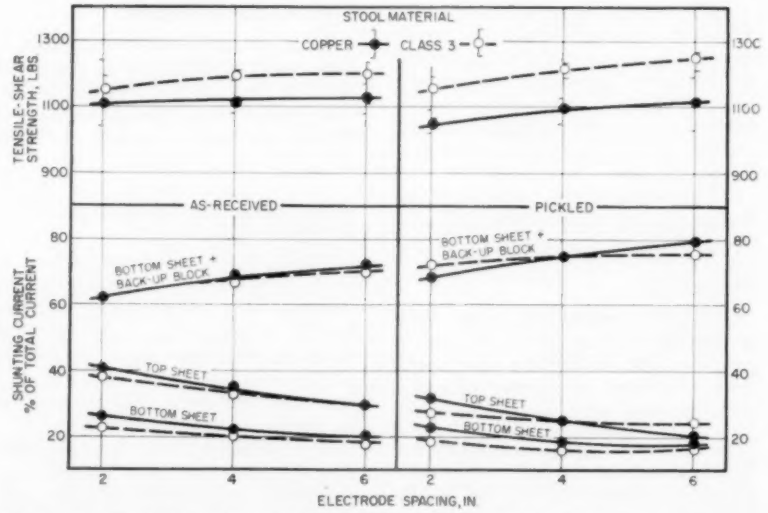

Fig. 6—The effect of stool material on strength and shunting currents, steel backup block, electrode force 480 lb.

block comparable to those observed with copper and RWMA Class 5 backup blocks.

Figure 8 shows a similar comparison of the effect of steel, copper and RWMA Class 5 backup blocks for an electrode force of 480 lb with RWMA Class 3 stools. The same general behavior described for the 700-lb electrode force above was observed with the 480-lb electrode force. In addition, slightly higher weld strengths were obtained with the same welding current with the 480-lb electrode force than with the 700-lb electrode force. As mentioned previously, this is to be expected since a reduction in electrode force results in increasing the initial value of the surface-contact resistance at the faying surface. Further evidence of this is provided by the slightly higher proportion of shunting current measured in the top sheet whenever the 480-lb electrode force was utilized. (Compare Figs. 5 and 6, as well as Figs. 7 and 8.)

Generalizations

The results of the present investigation are summarized in tabular form in Table 1. The first and second columns summarize the data for as-received stock with electrode forces of 700 and 480 lb, respectively. The third and fourth columns contain comparable data for the degreased-and-pickled stock. In all cases, the sum of the shunting current in the bottom sheet and the current in the backup block, in terms of percent of total current, has been tabulated as "Useful Shunting Current." From the data shown in Table 1 the following generalizations can be made:

1. The sum of the shunting currents in the bottom sheet and the backup block, termed the "useful shunting current" in Table 1, is essentially independent of the composition of the backup block. Apparently, the resistance of the backup block is negligible compared with the resistance in the balance of the secondary welding circuit.

2. Increasing the weld spacing increases the proportion of the total secondary welding current represented by the "useful shunting current" and results in increased weld strength. This may be readily seen by inspection of the data for 2-, 4- and 6-in. weld spacings in Table 1. For example, when welding as-received stock with a steel backup block and RWMA Class 3 stools, the "useful shunting current" increased from 63% of the total welding current with a 2-in. weld spacing, to 69% with a 4-in. spacing and to 72% with a 6-in. spacing. The corresponding weld strengths were 1060, 1140 and 1150 lb, respectively. A similar trend may be observed for other combinations of backup block and stool material with both as-received and degreased-and-pickled stock.

3. Decreasing the electrode force from 700 to 480 lb causes a slight decrease in "useful shunting current," but results in an increase in weld strength. As mentioned previously, this apparent paradox stems from the increase in the initial surface-contact resistance accompanying the decrease in electrode force.

4. The "useful shunting currents" with degreased-and-pickled stock average nearly 10% higher than those measured with the as-received stock. With degreased-and-pickled stock, the contact resistance at the faying surface is low, and therefore one would expect a greater percentage of the total current to pass through paths presented by the bottom sheet and the backup bar.

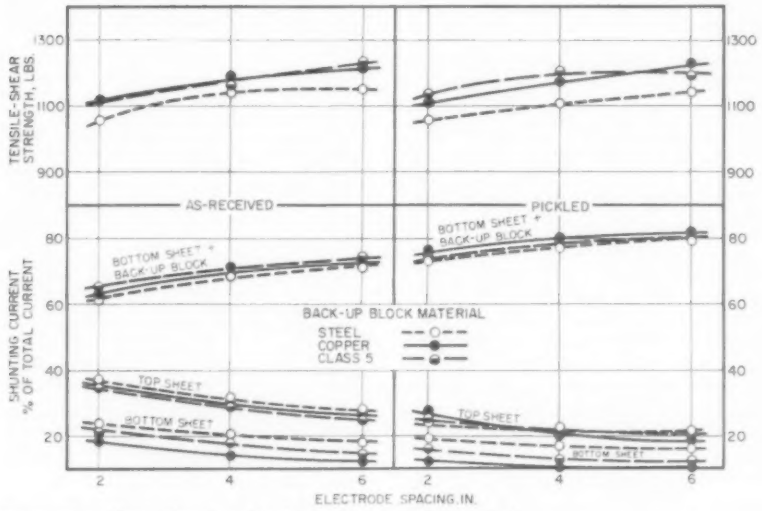

Fig. 7—The effect of backup block material on strength and shunting currents, Class 3 stools, electrode force 700 lb

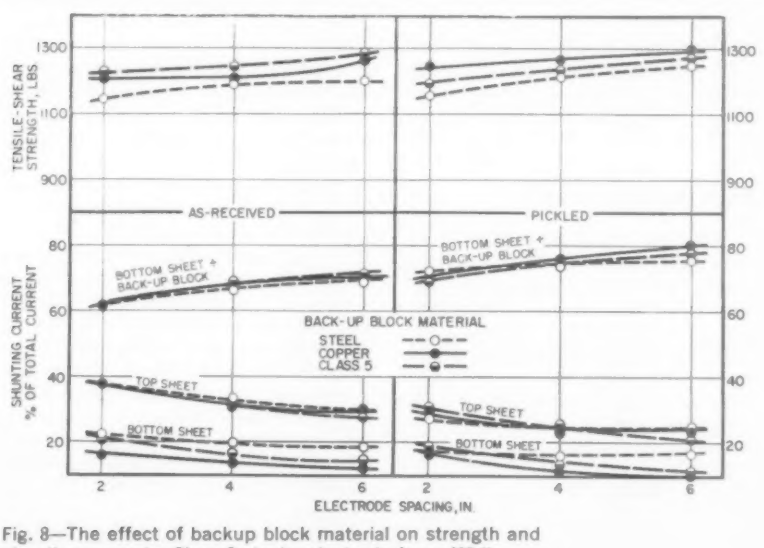

Fig. 8—The effect of backup block material on strength and shunting currents, Class 3 stools, electrode force 480 lb

Statistical Reliability of Data

The standard deviation for the tensile-shear strength was calculated as 30 to 35 lb for both as-received and degreased-and-pickled stock. The range of observed values has been indicated for each set of conditions by the brackets associated with each data point.

No indication of the range of observed shunting-current variation has been included on the plots since such indications made the interpretation of the plots more difficult. However, the precision of measurement averaged approximately ±1.5% for all current measurements, while the over-all accuracy averaged ±500 amp.

It is also of interest to note that the use of steel as a backup block material necessitated a 10% increase in secondary voltage in order to achieve the same current range employed with copper and RWMA Class 5 backup blocks. This reflects the higher impedance of the secondary circuit when steel is employed as a backup material. No difficulty was experienced in cooling of the backup material during this investigation, although in restricted quarters where small backup blocks would be required this might constitute a problem. However, since the resistivity of steel and the more expensive RWMA Class 5 material are roughly comparable, the increase in secondary impedance with steel must be primarily due to an increase in the inductive reactance. Since this does not result in an increase in the amount of energy dissipated by the secondary (inductive elements can only store energy), the steel should be no more difficult to cool than the RWMA Class 5 material.

Conclusions

The following summarizes the results obtained in this investigation of the series-spot welding of 0.036-in. auto-body steel, utilizing RWMA Class 2, 2-in. continuous-radius electrodes and a constant value secondary welding current of 12,400 amp.

1. The weld strength and the sum of the shunting currents in the bottom sheet and the backup block, termed the "useful shunting current," were essentially the same for copper, steel and RWMA Class 5 backup blocks (IACS conductivities of 100, 18 and 11.5%, respectively).

2. Increasing the weld spacing from 2 to 6 in. increased the useful shunting current by about 5 to 8%, and resulted in increased weld strength.

3. Decreasing the electrode force from 700 to 480 lb caused a slight decrease in useful shunting current, but resulted in an increase in weld strength.

4. Although the useful shunting currents with degreased-and-pickled stock averaged nearly 10% higher than those measured with as-received stock, the strengths of welds prepared from material with these two surface conditions were essentially the same.

5. The tensile-shear strength of series-spot welds made with a steel backup block and RWMA Class 3 stools (IACS cond. 52%) was consistently higher than the strength of welds made with steel backup blocks and copper stools (IACS cond. 100%), even though the useful shunting currents were the same.

6. Secondary voltages must be increased by approximately 10% to obtain the same secondary weld current and weld strength when steel backup blocks are substituted for copper or RWMA Class 5 backup blocks.

Acknowledgment

The authors wish to acknowledge the sponsorship of this experimental investigation by the Welding Research Council of the Engineering Foundation. They are further indebted to the membership of the Series Spot Welding Subcommittee, its chairman, John F. Cantalin, and John F. Randall, chairman of the Resistance Welding Committee, for guidance and advice during the investigation.

The authors also wish to thank Hugo Ferguson for his efforts in designing the multichannel integrating amplifier used in the measurement of shunting currents.

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RESEARCH NEWS

Uniform Bibliographical References

International research is often complicated by the different methods used for bibliographical references throughout the world. In order to help establish world-wide uniformity for bibliographical references, the Documentation Technical Committee of the International Organization for Standardization (ISO) has developed a recommended standard which is available from the American Standards Assn.

The new recommendation is listed as "ISO Recommendation R 77—Bibliographical References—Essential Elements" and may be obtained at 60 cents each from the American Standards Assn., Department PR134, 10 E. 40th St., New York 16, N. Y.

Brittle-fracture Research

Four Navy research reports on stress and crack potential of welded steel plate, including crack inspection by radioisotopes, have been released to industry through the OTS, U. S. Department of Commerce. The reports are:

Weld Flaw Evaluation. S. T. Carpenter and R. F. Linsenmeyer, Swarthmore College, for Bureau of Ships, U. S. Navy. July 1958. 121 pages. (Order PB 161322 from OTS, U. S. Department of Commerce, Washington 25, D. C., $2.75.) The mechanics of brittle fracture was investigated at different temperatures, by means of simulated flaws in selected materials. The theory employed was based on the work of A. A. Griffith and G. R. Irwin.

Evaluation of Weld-joint Flaws as Initiating Points of Brittle Fracture. R. P. Sopher, A. L. Lowe, Jr., and P. J. Rieppel, Battelle Memorial Institute, for Bureau of Ships, U. S. Navy. Aug. 1958. 55 pages. (Order PB 161323 from OTS, U. S. Department of Commerce, Washington 25, D. C., $1.50.) The objective of this project was to learn how brittle fracture begins. Investigation was confined to flaws no longer than 4 in. Some fractures resulted from an applied stress of less than 6000 psi.

The Investigation of Radioisotopes

(Continued on page 341-s)

Calculations for Temperature Response in Spot Welds

Objective of calculation is to provide a conservative determination for the time required by a weld to reach fusion temperature

BY G. R. ARCHER

ABSTRACT. The nature of temperature response in spot welding has an important bearing upon the techniques used for control. The intention of these calculations is to provide insight into the response of the material. This type of calculation shows how the frequency, level and phase control of the power source affects temperature response for single-phase welding. The calculation also shows how the thickness and thermal characteristics of individual alloys will affect the temperature response.

General conclusions directed at problems of foil gage welding have been presented in an earlier paper.[1]

Calculation of Weld Heating

The objective of this calculation is to provide a conservative determination for the time required by a weld to reach fusion temperature. This time behavior sets the dynamic response of the weld.

Several assumptions precede the calculation.

1. Heat is assumed to flow in only one direction, straight through the sheets and not to fringe outward. Both heat and electricity very nearly flow directly between the electrodes so that only one dimension needs to be considered mathematically. This assumption is easily justified in the cases of very thin gages. Thick gages experience more fringing of the heat and current outward.

2. Temperatures are measured upward from the electrode temperatures. The variable U, which signifies temperature, is actual temperature minus the electrode temperature. This does not affect the time determination that is the output of this calculation.

3. The material being welded is considered to be isotropic and homogeneous; which is to say, the heat flows equally well in any direction and there is no necessity for considering thermal conductivities as oriented to crystalline formation.

4. Specific heat, thermal conductivity and electrical resistivity are assumed to be constant for all the temperatures within the solution. This is not an accurate assumption, but it should not seriously disturb the general conclusions derived from this analysis.

The classical expression for heat flow is:

$$\nabla^2 U = \left(\frac{1}{\alpha^2}\right)\frac{\delta U}{\delta t} \qquad (1)$$

where U is temperature above the reference electrode temperature, t is time, $\alpha_2 = k/c\rho$, where k = thermal conductivity, c = specific heat and ρ = density.

One of our assumptions concerned the fact that heat is assumed to flow from the central interface between two sheets outward to the electrodes in straight lines. We can then define the distance along the material being welded as x. So $x = 0$ at the central interface and $x = th$, the thickness of the material at the electrodes. Thus $x = +th$ at one electrode and $x = -th$ at the other electrode. The one dimensional expression for eq 1 is then:

$$\frac{\delta^2 U}{\delta x^2} = \left(\frac{1}{\alpha^2}\right)\frac{\delta U}{\delta t} \qquad (2)$$

Assume now that heat is introduced into the spot weld with direct current. This is a temporary assumption but it allows us to say that, if the heat applied does not vary, then eventually there will be no variation of temperature with time. That is to say, the partial derivative of temperature with respect to time will sometime become 0 and eq 2 now becomes 3 which indicates steady state:

$$\frac{d^2 U_{ss}}{dx^2} = 0 \qquad (3)$$

which integrates out to the solution:

$$U_{ss} = C_1 + C_2 x \qquad (4)$$

This is the steady-state solution which constitutes the eventual temperature that will occur within a single sheet of a two-sheet pile-up being heated by heat that is generated at the central interface between the two sheets. To calculate the constants C_1 and C_2, we can find that where $x = 0$ at the central interface, the temperature equals C_1 and that temperature can be found by computing the temperature rise due to internal heating concentrated at the interface dropping through the thermal resistances of the sheets. In accordance with Reference 2, the steady-state temperature can be determined in terms of the voltage developed across a weld as:

$$U_{ss} = 3.5 \times 10^4 E^2 \left[1 - \left|\frac{x}{th}\right|\right] \qquad (5)$$

where the temperature at the center between two sheets is given as a direct relationship of the over-all weld voltage squared and the temperature decreases linearly to 0 when x equals the thickness in either the positive or negative X direction.

The total solution for temperature within a resistively heated spot weld is the steady-state solution just found plus a dynamic solution that can be found by the classical techniques. The dynamic solution for the expression in the form of eq 2 can be found by separation of variables noticing that the dynamic solution will be some function of x and t, time, so that we can rewrite eq 2 as: $U_d = X(x) \cdot T(t)$ which becomes (primed terms are derivatives):

$$X''T = \left(\frac{1}{\alpha^2}\right) XT' \qquad (6)$$

$$\frac{X''}{X} = \frac{T'}{\alpha^2 T} = -N^2 \qquad (7)$$

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Table 1

Heating described in Fig.	Applies to 60 cps for the following thicknesses in inches for M	Aluminum	Stainless steel	Carbon steel	Applies to 600 cps for the following thicknesses in inches for M	Aluminum	Stainless steel	Carbon steel
2	60	0.0765	0.018	0.020	600	0.024	0.0058	0.006
3	120	0 054	0.013	0.014	1,200	0.017	0.0041	0.0045
4	300	0.034	0.0082	0.009	3,000	0.011	0.0026	0.0028
5	600	0.024	0.0058	0.006	6,000	0.005	0.0018	0.002
6	1200	0.017	0.0041	0.0045	12,000	0.003	0.0013	0.0014
7	3000	0.011	0.0026	0.0028	30,000	0.0024	0.0008	0.0009
8	1000	0.005	0.0018	0.002	60,000	0.0017	0.0006	0.0006

This is a standard sort of operation which says that, since the functions of distance and time are wholly independent and equal, they must be equal to some constant which we set at $-N^2$. We can then write eq 8 and 9 that have solutions given as eq 10 and 11.

$$X'' + N^2X = 0 \quad (8)$$

$$T' + \alpha^2N^2T = 0 \quad (9)$$

$$X(x) = C_3 \sin Nx + C_4 \cos NX \quad (10)$$

$$T(t) = C_5e^{-(\alpha N)^2t} \quad (11)$$

We can then string out the steady-state solution with the dynamic form of solution just found to read that the dynamic solution U_d, which is $X(x)T(t)$, plus the steady-state solution, found as eq 5, gives us a total expression of temperature that is eq 12.

$$U = U_{ss} + U_d = 3.5 \times 10^4E^2\left[1 - \left|\frac{x}{th}\right|\right] + e^{-(\alpha N)^2t}[c_6 \sin Nx + c_7 \cos Nx] \quad (12)$$

It is now necessary to define the constants c_6 and c_7 and N in terms of a Fourier expansion of the steady-state solution. At time 0, the Fourier expansion must equal the negative of the steady-state solution since there is no temperature change at the instant the d-c voltage is applied. The entire expression can be phrased in terms of a cosine series if we note that for $x = 0$ the cosine is 1 and then arrange the term N such that when $x = \pm th$ the cosine is an odd multiple of 90 deg which gives 0 for the cosine term. The redefinition of N as $n\pi$ divided by $2th$ allows us to rewrite the expression as shown in eq 13 where c_n is the coefficient associated with each of an infinite number of cosine terms modified by exponentials, where n is 1, 3, 5, 9, . . . c_n (odd integers).

$$U = 3.5 \times 10^4E^2\left[1 - \left|\frac{x}{th}\right|\right] - \sum_{n=1}^{n\omega} C_ne^{-(an\pi/2th)^2t} \cos \frac{n\pi x}{2th} \quad (13)$$

As n increases, the exponential dies out faster. The slowest exponential in the complete expression for weld temperature is the exponential associated with $n = 1$. In this case, we have the longest time-dependent solution and, therefore, working with this solution alone gives us the most conservative viewpoint of how long it takes a weld to reach a given temperature.

Simplifying the over-all expression for temperature to include only the temperature at the interface where $x = 0$ and to include most conservatively only the longest time constant, we have the expression given as eq 14 where U_1 is this simplified solution:

$$U_1 = 3.5 \times 10^4E^2[1 - e^{-(\alpha\pi/2th)^2t}] \quad (14)$$

This solution in turn, corresponds to the differential equation given as eq 15.

$$U_1' + \left[\frac{\alpha\pi}{2th}\right]^2 U_1 = 3.5 \times 10^4E^2\left[\frac{\alpha\pi}{2th}\right]^2 \quad (15)$$

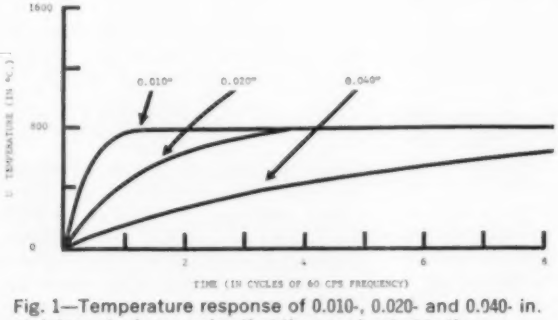

Fig. 1—Temperature response of 0.010-, 0.020- and 0.040- in. stainless steel, assuming that they are heated to the same 800° C temperature with direct current

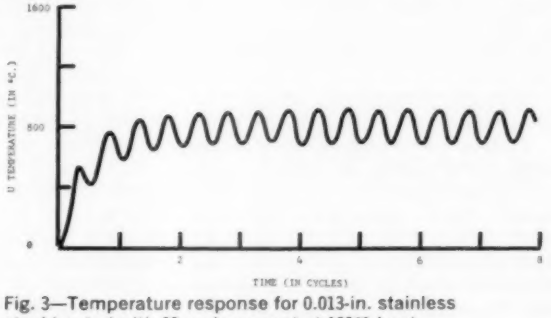

Fig. 3—Temperature response for 0.013-in. stainless steel heated with 60-cycle current at 100% heat

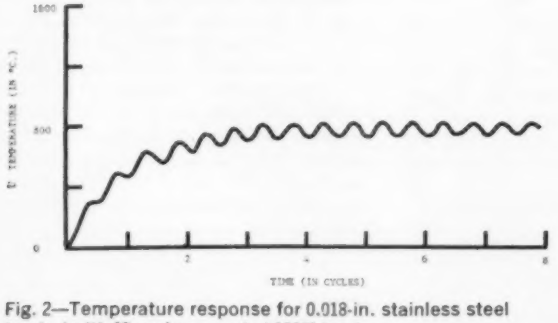

Fig. 2—Temperature response for 0.018-in. stainless steel heated with 60-cycle current at 100% heat

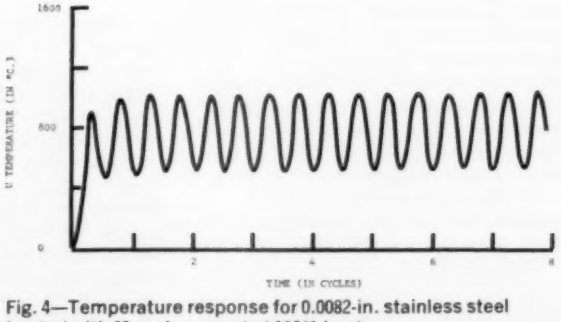

Fig. 4—Temperature response for 0.0082-in. stainless steel heated with 60-cycle current at 100% heat

This simplified differential equation can now be used to find the conservative temperature response of a weld to a-c heating of the type we have in single-phase resistance-welding practice. The calculations made for a-c heating of resistance welds were performed with a digital computer and, for this reason, the differential equation was converted into an equivalent form of difference equation by saying that the derivative of U_1 with respect to time equals U_1 at time interval, n, minus U_1 at time interval time $n - 1$ the difference equation is given as eq 16:

$$U_1(n) = \frac{U_1(n-1) + 3.5 \times 10^4 E^2 [\alpha\pi/2th]^2}{1 + [\alpha\pi/2th]^2} \quad (16)$$

The computer solution was run for 3 cases of single-phase welding practice. The first was 100% heat (sinusoidal), the second was a simulation of 50% heat in which the voltage applied to the weld was assumed to be sinusoidal with an equal amount of time between sinusoidal pieces so that the rms value of the voltage was reduced by $^1/_2$. The third case of heating involved a simulation of 25% heating, again where the sinusoidal voltage was on only 25% of the time. The computer calculated the sinewave at 40 positions, 9 deg increments. The value M which lumps together the thermal characteristics with the thickness of the metal being welded, was entered into the computer over a range of values which can be normalized so that the computer solution can be applied to differing frequencies and not just 60-cycle welding practice. With this normalization, to obtain the equivalent M for a different frequency, take the value given for 60 cycles, divide by 60 and multiply by the new frequency. This presents the data for an equivalent M at a differing frequency. Since high frequency is often mentioned as the possibility for thin gages, 600-cycle a-c power is considered, and thin gages are shown for 600 cycle.

Table 1 shows how the data plotted referred to thicknesses for aluminum, stainless steel and low-carbon steel for both frequencies, 60 and 600 cps.

The rms value of the voltage used in the computer solution for 100% heat would produce an 800° C steady-state temperature and corresponds to the solution for eq 14 with an equivalent amount of d-c applied voltage. Figure 1 shows the response to d-c heating for this equivalent d-c input for three thicknesses of stainless steel. The thicknesses plotted are 0.010, 0.020 and 0.040 in. The solutions for the U_1 of these 3 gages are given over 8 cycles of 60-cycle weld current. Notice that the temperature reaches a steady value in a little over 1 cycle for 0.010 in. material, in about 4 cycles for 0.020 in. material and would require about 16 cycles for the 0.040-in. material. These responses serve as a reference point against which the a-c heating data can be evaluated.

Figure 2 shows the response given by 100% heating of the gage to the a-c heating for material with the characteristics of 0.018-in. stainless steel. Notice that the temperature tends toward the 800° C value and oscillates around that value depending on the instantaneous value of the a-c. The variations around 800° C after about 4 cycles run ±63° C, or slightly over 5% of the average value.

Figure 3 shows the response to heating equivalent to a gage of 0.013-in. stainless steel. For this material the variation around the average value tends to about ±123° C, about 15% of the average value.

Figure 4 shows the response to heating equivalent to a gage of 0.0082-in. stainless steel. For this material the variations around the average value tend to 280° C, that is, ±35% of the average value.

In Figure 5, the response shown is comparable to 0.0058-in. stainless steel. The variations around the average value tend to 460° C or ±57%. The maximum temperature for the 8th cycle in this gage is a little over $^3/_{10}$ of a degree greater than the maximum temperature

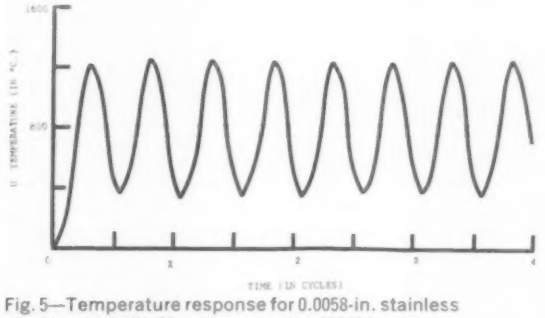

Fig. 5—Temperature response for 0.0058-in. stainless steel heated with 60-cycle current at 100% heat

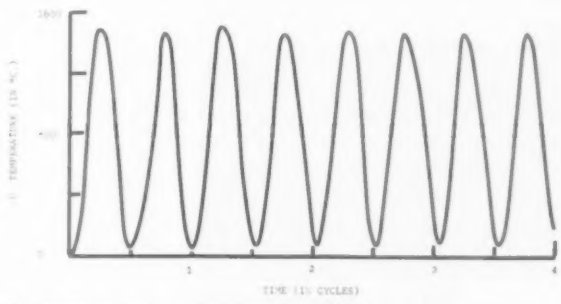

Fig. 7—Temperature response for 0.0026-in. stainless steel heated with 60-cycle current at 100% heat

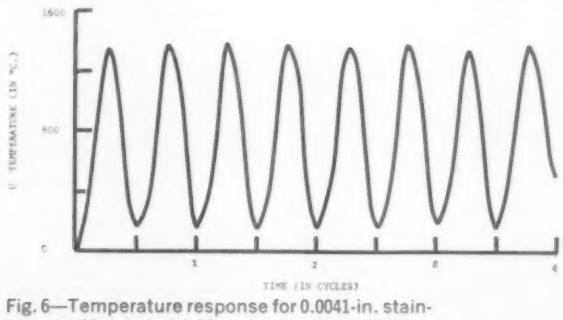

Fig. 6—Temperature response for 0.0041-in. stainless steel heated with 60-cycle current at 100% heat

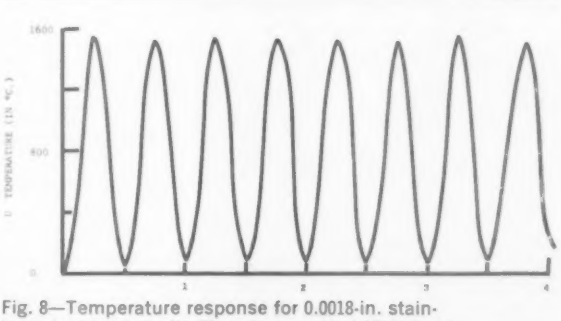

Fig. 8—Temperature response for 0.0018-in. stainless steel heated with 60-cycle current at 100% heat

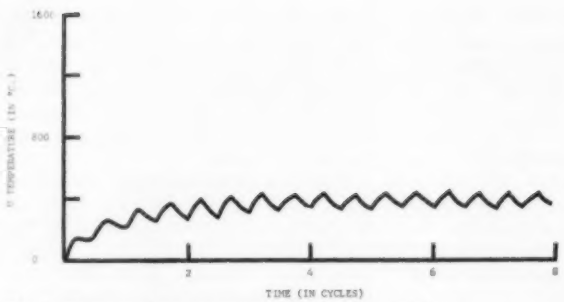

Fig. 9—Temperature response for 0.018-in. stainless steel heated with 60-cycle current at 50% heat

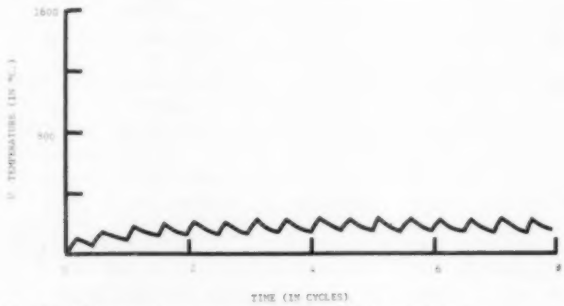

Fig. 10—Temperature response for 0.018-in. stainless steel heated with 60-cycle current at 25% heat

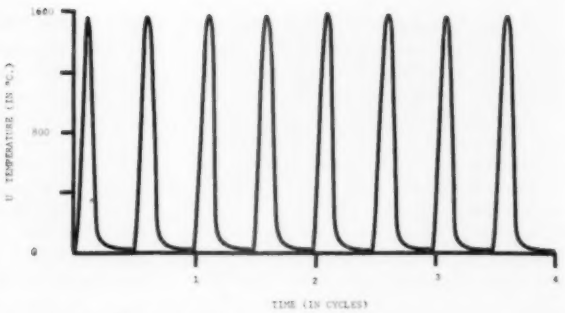

Fig. 11—Heating for 0.0018-in. stainless steel with 60-cycle current at 50% heat

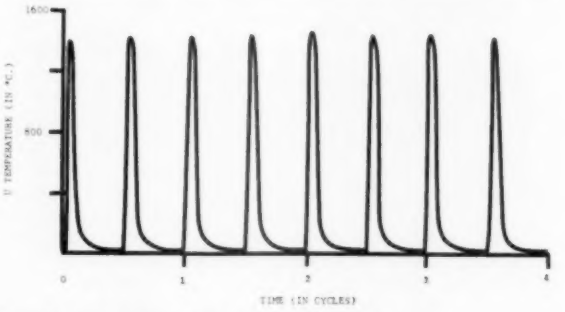

Fig. 12—Heating for 0.0018-in. stainless steel heated with 60-cycle current at 25% heat

reached during the first cycle. This variation of $^3/_{10}$ of a degree out of a temperature of 1260° is smaller than we can show in plotting so that data are plotted for only 4 cycles for the following figures which represent thinner gages.

Figure 6 which represents heating of material equivalent to 0.004-in. stainless steel shows that the final variation around the average temperature comes to 630° C.

Figure 7, which represents heating of 0.0026-in. stainless steel, shows variations around the average temperature of 747°.

Figure 8, which represents heating of 0.0018-in. stainless steel, shows variations around the average temperature of 773° C. These variations, something over 90% of the average value, indicate that the response to heating is more dominated by the instantaneous value of the a-c heating voltage than by its rms value. Furthermore, the material cools to within 27° C of the 0 temperature at the instant when the voltage is reversing and is 0.

Figures 9 and 10 show 50 and 25% a-c heating, respectively, for a gage equivalent to 0.018-in. stainless steel. When these results are compared with those shown in Fig. 2 for 100% heating of the same gage, it is quite noticeable that, for this thickness, the decrease in rms value of the weld voltage produces a proportionate decrease in the average temperature to which the metal tends.

In Figs. 11 and 12, the response is shown for gage comparable to 0.0018-in. stainless steel again for heating of 50 and 25%, respectively. In the 4 cycles of heating shown here, it is apparent that the temperatures still tend toward the high values compared with those given in 100% heating in Fig. 8. This again demonstrates how the faster response to heating present in thinner gages makes them more dependent on the instantaneous rather than the average values of the driving voltage.

References

1. Archer, G. R., "Successful Welding of Foil Gages," THE WELDING JOURNAL, **39** (4), 343–347 (1960).

2. Archer, G. R., "A New System for Automatic Feedback Control of Resistance Spot Welding," *Ibid.*, **38** (10), 987–993 (1959).

List of Symbols Used

C_1 to C_n = constants.
c = specific heat.
$d(\ )$ = derivative.
e = natural log base.
E = voltage developed across a weld.
k = thermal conductivity.
$M = \frac{(\alpha\pi)^2}{(2th)^2}$ = large values imply fast heating.
n = increments of time used by computer and (for odd integers) characteristic numbers in complete solution for temperature.
N^2 = characteristic numbers.
t = time measured from the time weld heat starts.
T = a function of time.
th = thickness.
U = temperature °C measured from an arbitrary point.
U_{ss} = steady temperature.
U_1 = temperature at interface (simplified).
x = the distance from the central interface of a weld measured toward the electrodes.
X = a function of x.

(NOTE: primed values of U_1, T and X are derivatives.)

α^2 = Clerk-Maxwell's constant of thermometric conductivity (high values indicate fast response to heating).
$\delta(\ )$ = partial derivative.
π = 3.1416.
ρ = density.
Σ = a sum of (solutions).
$\nabla^2(\ )$ = the operator for LaPlace's differential equation.

Fundamental Studies of Ultrasonic Welding

Studies related to ultrasonic welding are made to determine the mechanism of bonding, the effects of welding variables and the effects of material factors

BY N. E. WEARE, J. N. ANTONEVICH AND R. E. MONROE

ABSTRACT. An understanding of the fundamental factors involved is important in the use of any welding process. Studies related to ultrasonic welding were made to determine the mechanism of bonding, the effects of welding variables and the effects of material factors. After preliminary experiments indicated the importance of heat generated at the weld interface, apparently from a simple friction reaction, a simple weld joint was used for further studies of the mechanism of bonding. Sphere-to-plate welds involving a single interface were made which allowed precise measurement of phenomena occurring during welding.

Much of the data obtained thus far has indicated that bonding is due to the formation of a thin molten film in the interface. However, since no definite proof of this mechanism was obtained, there remains the possibility of solid-state bonding. A study of literature regarding friction has aided in the derivation of some equations which may be helpful in mathematically expressing the important factors involved in ultrasonic welding conditions. Additional work is needed to integrate into these equations the continuing changes in properties and contact area that occur during welding.

Studies were made to determine the effects of welding conditions on the properties of ultrasonic spot welds. Aluminum (1100) was used in most of these studies. The strength of aluminum ultrasonic spot welds increases in a nearly linear manner with increased welding-tip displacement. Strength rises rapidly with increases in welding time to a maximum value in the first few seconds and then remains constant. Increased clamping pressure when other factors are constant increases weld strength linearly to a maximum value at which strength then levels off or becomes less at higher clamping pressures. No differences in weld properties were noted for aluminum welds made with 3- or 6-in. radius weld tips with either rough or smooth tip surfaces. The effects of weld tip or anvil material were not studied extensively; however, it was shown that stronger welds and higher interfacial temperatures were obtained if the weld tip and anvil material had a low thermal conductivity.

The strength of welds in aluminum was not affected by removing the oxide film before welding. Welds made in gold indicated that bonds were readily made in soft metals possessing no surface oxide. As the thickness of material or degree of prior cold work increased, higher energy inputs were required to obtain ultrasonic welds.

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Introduction

Ultrasonic welding is only a recent development in the metals-joining field. The work of Jones, *et al.*[1-5] has been aimed primarily at determining whether or not bonds could be made in various metal combinations and configurations. Equipment development also has been emphasized.[1-5] Since the process is a newcomer, not much is known about the fundamentals of ultrasonic welding and the mechanism of bonding is even less understood. At present, reliable predictions of the ease of welding, joint properties, welding conditions and optimum material finish, temper, etc., cannot be made regarding ultrasonic welding. Once the fundamental and basic mechanisms are clearly understood, it should be a straightforward task to design suitable equipment and adapt it to the welding of various materials and types of joints.

As part of a program conducted for Wright Air Development Center, fundamental studies of ultrasonic welding were made to obtain information for use in evaluating both the potential usefulness of the process and the process limitations. Results of studies on welding heat-resisting alloys[6] and the early explorations of ultrasonic welding[1,2] are excellent illustrations of the need for fundamental information. Three areas were considered of first importance for fundamental studies:

1. An understanding of the mechanism of bonding.
2. Understanding of the effects of changes in welding conditions.
3. Understanding of the effects of changes introduced by the material or materials being welded.

Eventually, an explanation combining the important factors from these areas may be developed which will give a satisfactory explanation of the ultrasonic-welding process. The work described in this paper represents the initial attempts to achieve this objective. At this writing, the conclusions should be viewed as tentative, subject to verification by continued experimentation and analysis.

Experimental Procedures

The welding equipment used in this work has been described in a previous paper.[7] Figure 1 shows a block diagram of the welding system, instrumentation and energy flow in the system.

A sphere-plate joint was selected to investigate some of the fundamental factors involved in ultrasonic welding. The sphere-plate joint differed from normal ultrasonic-weld joints as shown in Fig. 2. All but one of the interfaces present in the normal ultrasonic weld were eliminated by welding the Monel spherical weld tip to a rigid copper bar. This eliminated variables present because of slippage at the additional interfaces, allowed controlled conditions to be used throughout the study, and made it possible to get accurate measurement of the variables studied. Direct measurements of the dis-

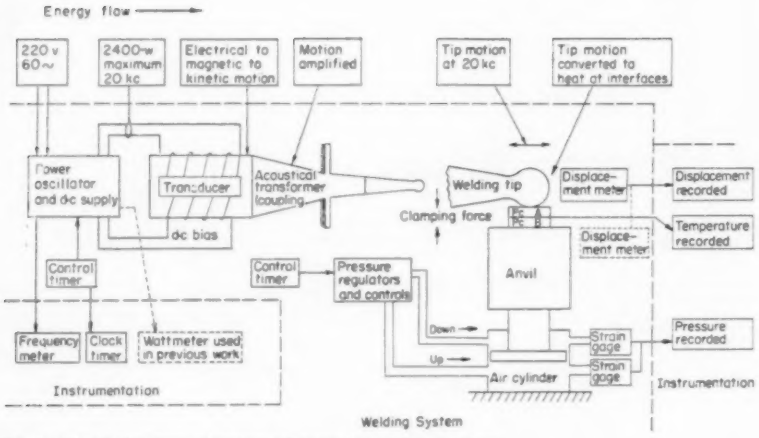


Fig. 1—Block diagram showing ultrasonic-welding system, instrumentation and energy flow

placement of one joint component relative to the other during a welding cycle were obtained. The force required to break the Monel copper weld was recorded using a strain gage calibrated in terms of the disengaging force. This type of loading approximates the conditions of testing a cross-tension specimen.

Experimental Results

Studies were made with sphere-plate and normal spot welds between two pieces of sheet material to determine the effects of the welding conditions, time, clamping pressure and tip displacement on weld strength. Sphere-plate welds were used to study the effects of welding conditions on weld-spot dimensions and temperature and the effect of the incident angle of the vibration on weld strength. The effects of material and equipment-design variables were studied using normal welds. Results of these tests are discussed hereafter.

Weld-area Temperature Studies

Preliminary studies using normal welding procedures indicated that heat generated by surface motion between parts was an important factor in ultrasonic welding. A series of sphere-plate welds was made in an attempt to obtain more accurate temperature measurements. The copper-Monel junction at the weld site was used as a thermocouple and temperature was recorded on an oscillograph. The data obtained in these studies are presented graphically in Fig. 3. These data suggest that an optimum welding time exists for given welding conditions. Continued application of ultrasonic energy beyond this optimum time does not increase the interfacial temperature and may have an adverse effect on weld strength. It is also noted that there appears to be a minimum temperature before significant metallurgical bonding occurs.

In later tests, the thermal electromotive forces generated were portrayed upon the screen of an oscilloscope. Work reported by Bowden and Tabor[8] indicated that such a measuring technique might show temperatures near the melting point of copper. The expected high-temperature spikes in the oscilloscope trace were not observed. The maximum temperatures measured were near 450° F. Under conditions of low clamping force and high ultrasonic motion over a long period of time, thermal emf's were noted but none indicated temperatures near the melting point of copper. Yet, at times, under these conditions, particles of molten copper could be observed at the edge of the weld, and the copper sample became red hot. It is possible that slippage took place only near the periphery of the contact area and complete sliding did not occur between surfaces. This might cause the thermal emf's generated in the slippage area to be shorted through the nonslipping contact area. This would result in an emf reading at the couple terminals much lower than actual local emf's at the interface. Another possibility is that a molten copper junction with Monel may not have the same temperature response that a solid-phase copper-Monel junction would have.

A number of experiments were

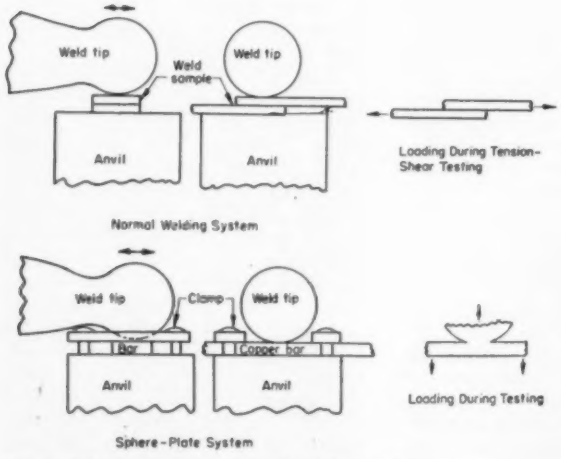


Fig. 2—Sphere-plate and normal welding systems

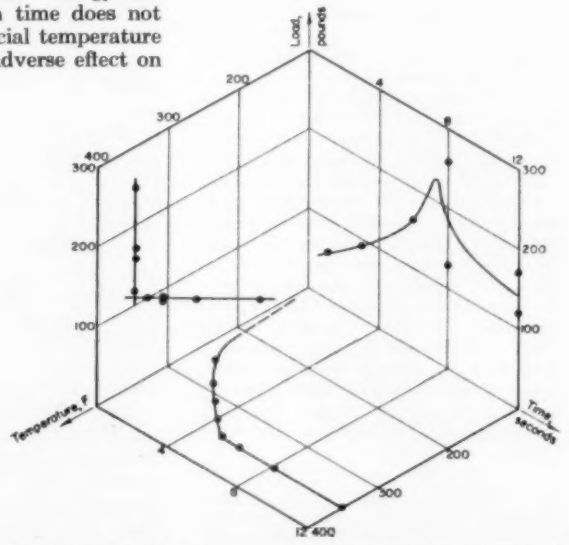


Fig. 3—Relationship among breaking load, weld time and peak temperature for copper-Monel weldment. Variable weld time with Type 1C, 3-in. radius tip. Tip displacement, 1.2 mils; clamping force, 83 lb

conducted in which a small specimen of material was caused to slide ultrasonically over a glass or quartz plate. Metal samples of aluminum, copper and molybdenum were clamped with a plate of glass or quartz between the welding tip and anvil of the ultrasonic-welding unit. The glass and quartz had reflecting surfaces on the underside to allow observation of any hot spots occurring. The intent here was to ascertain whether or not temperatures higher than the above-recorded temperatures could be reached.

From hot spots observed, it was concluded that temperatures greater than 520° C. (970° F.) could be reached, since hot spots cannot be observed below this temperature, and temperatures near 1400° C. (2550° F.) occurred since white-light emission was observed with molybdenum samples. Copper and aluminum samples produced red to white light emission. The color of the light emitted was dependent upon the displacement and clamping force.

Welding Conditions and Weld Strength

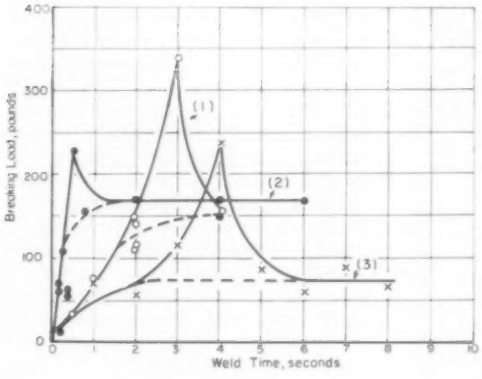
The relationship of weld strength to weld time for sphere-plate welds made at various weld-tip displacements is shown in Fig. 4. These curves indicate that, for a given displacement and clamping force, there is a critical weld time above which strength drops to a constant value. If points near the critical time are neglected, an exponential relationship between weld time and weld strength is indicated.

Figure 5 shows the effect of weld time on the strength of ultrasonic spot welds in 0.040-in.-thick 1100-O and 1100-H18 aluminum made at various conditions. Curves similar to these also were obtained for other weldments investigated. A similarity exists between curves showing the strength versus weld time and temperature generated during welding versus weld time. As shown in Fig. 5, low tip displacement and clamping pressures required longer weld times to obtain the maximum strength. As displacements and clamping forces were lowered below the values given for Fig. 5, weld strength became very low and erratic regardless of weld times used.

Figure 6 shows the relationship between breaking load and clamping force for sphere-plate welds. These curves show that the weld strength increases nearly linearly with clamping force but reaches a maximum value at given conditions of weld time and displacement.

The effect of clamping pressure on the strength of ultrasonic welds in aluminum also were studied. This relationship is shown in Fig. 7 and is similar to the relationship shown in Fig. 6. Other displacements and weld times produced similar curves for normal-type welds.

Figure 8 shows the relationship between breaking load and tip displacement for sphere-plate welds. Below some minimum displacement, the weld strength is negligible. Figure 9 shows the effect of tip displacement on the tensile-shear



Curve No.	Weldment	Tip Displacement, mils	Clamping force, lbs	Weld Time, sec
1	Copper-Monel	0.9	100	Variable
2	Ditto	1.4	100	Ditto
3	Ditto	0.7	100	Ditto

Fig. 4—Relationship between breaking load and weld time

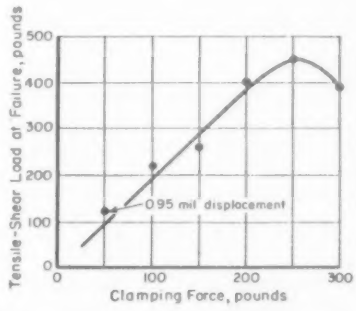
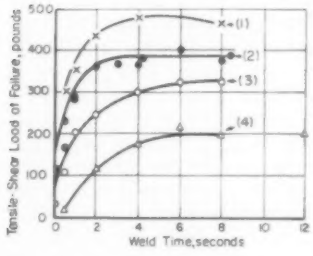
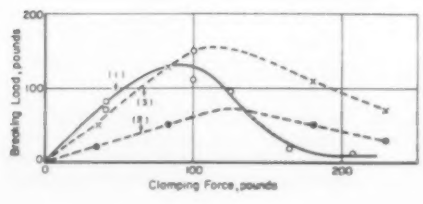


Fig. 7—Variation in weld strength with clamping force for ultrasonic spot welds in 1100-H18 aluminum



Curve No.	Material	Sheet Thickness, in.	Cleaning	Tip Displacement, mil	Clamping Force, lb	Weld Tip Type	Weld Tip Radius, in.	Anvil Type	Anvil Radius, in.
1	1100-O A-1	0.040	NaOH HNO_3	1.3-1.4	200	1 C	3	3	Flat
2	1100-O A-1	0.040	NaOH HNO_3	1.2-1.3	200	1 C	3	3	Flat
3	1100-O A-1	0.040	NaOH HNO_3	1.05-1.3	100	1 C	3	3	Flat
4	1100-O A-1	0.040	NaOH HNO_3	0.7-0.9	200	1 C	3	3	Flat

Fig. 5—Variation of weld strength with weld time for two material tempers, two clamping forces and two degrees of tip displacement for ultrasonic spot welds in aluminum



Curve No.	Weldment	Monel Tip Radius, in.	Copper Thickness, in.	Tip Displacement, mils	Clamping Force, lbs	Weld Time, sec
1	Copper-Monel	1/2	0.125	0.9	Variable	2
2	Ditto	3	0.032	0.8	Ditto	4
3	Ditto	3	0.032	1.25	Ditto	4

Fig. 6—Relationship between breaking load and clamping force

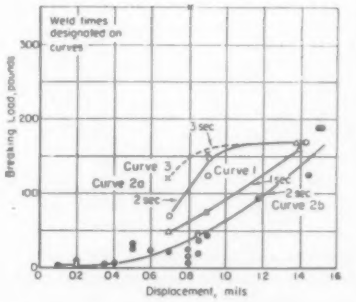
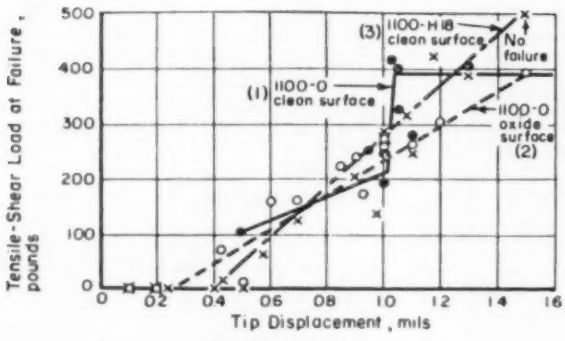
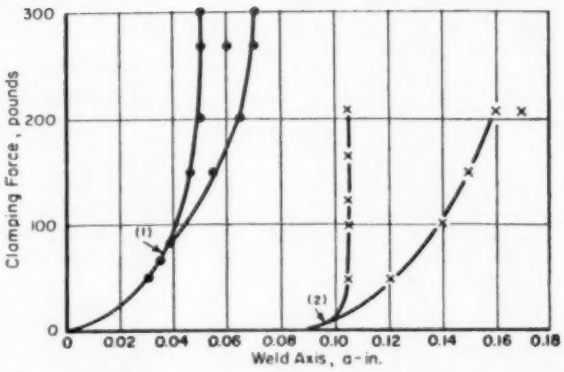


Fig. 8—Relationship between breaking load and ultrasonic displacement. Copper-Monel welds at 100-lb clamping force



Curve	Cleaning	
		Clamping Force: 200 lb
1	$NaOH-HNO_3$	Weld Time: 4 sec
2	Degrease	Weld Tip: Type 1C, 3-in. radius
3	$NaOH-HNO_3$	Anvil: Type 3, flat radius

Fig. 9—Variation of weld strength with tip displacement for two material tempers and two degrees of surface cleanliness for ultrasonic spot welds in aluminum



(1) Minor and major axes of contact area with no vibrations
(2) Minor and major axes of weld with 0.9-mil motion for 2 sec.

Fig. 10—Relationship between weld minor and major axes and clamping force for copper-Monel weldment

strength of ultrasonic welds in 0.040-in.-thick aluminum alloy. As can be seen from the plot, strength increases nearly linearly with increasing tip displacement for 1100-H18 aluminum. This linear relationship was noted for copper-Monel welds and in other welding studies made using aluminum (see Figs. 14, 15 and 17) and gold (Fig. 16).

The curve obtained for the 1100-O aluminum appears to have a break, that is, it went through a transition from low to high strength in a short range of tip displacement. This behavior was not noted in other studies made using the 0.040-in.-thick 1100-O aluminum sheet.

Curve 1 in Fig. 9 indicates that for 0.040-in.-thick 1100-O aluminum, optimum weld strength was not achieved until the tip displacement exceeded 1 mil. Metallographic examinations of all types of welds made during this study indicate that as tip displacement increased weld area increased, the extent of plastic deformation increased, and, in the case of welds between similar metals, joint interfaces tended to be more nearly eliminated. Plastic deformation in the form of "turbulence" at the edge of the weld was common for most ultrasonic welds. At high tip displacement, cracking became common in some joints studied.

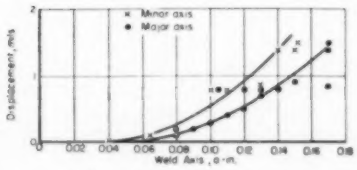


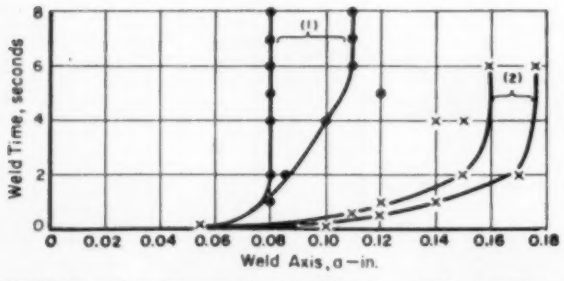
Fig. 11—Relationship between weld-tip displacement and weld minor and major axes. Copper-Monel weld with a clamping force of 100 lb and weld time of 2 sec. Sphere of $^5/_{16}$-in.-radius Monel

Relationship of Weld Axes to Welding Conditions

Measurements of weld dimensions were made during the sphere-plate experiments. The weld areas were somewhat elliptical, so the major and minor axes of the apparent ellipses were measured. Figure 10 shows the relationship between the weld axes and clamping force with and without ultrasonic motion given to the Monel tip. Even when no ultrasonic motion occurred, the deformed area was not circular, indicating that the welding tip was not exactly spherical. Figures 10 through 13 show how weld axes vary with weld-tip displacement, weld times, clamping force, and weld-tip incident angle.

Effect of Incident Angle

A series of welds was made with the Monel weld tip vibrating with constant displacement amplitude



(1) Minor and major axes of weld with 0.7- and 0.9-mil motions
(2) Minor and major axes of weld with 1.4-mil motion

Fig. 12—Relationship between weld minor and major axes and weld time for copper-Monel weldments. Clamping force, 100 lb

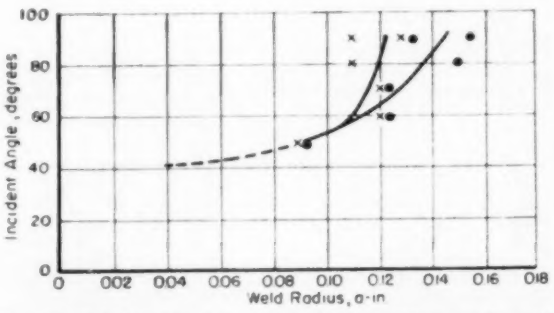


Fig. 13—Relationship between weld-tip incident angle and average weld radius. Copper-Monel weld with a clamping force of 100 lb and weld time of 2 sec. Monel sphere of $^5/_{16}$-in.-radius and 1.1-mil weld-tip displacement at 90-deg incident angle

at various angles with respect to the copper bar. Maximum weld strength was obtained when the incident angle was 90 deg, i.e., the ultrasonic displacement normal to clamping force. Figure 14 shows the relationship between breaking load and incident angle. Weld strength decreases with incident angle, reaching an apparently constant low value for incident angles below 40 deg. This would indicate that only the horizontal component of welding motion contributes to weld strength. The minimum horizontal displacement necessary for welding is in close agreement with that indicated by curves of Fig. 8.

Variables Related to Equipment Design

Some variables can be introduced in ultrasonic welds because of the equipment design. Of primary importance are the weld tip and anvil configuration, material and surface condition.

The effect of weld-tip geometry was briefly studied using aluminum samples. No significant difference could be found for strength of welds made using either a 6- or 3-in.-radius weld tip. This is illustrated in Fig. 15. Other investigators who studied the effect of tip radii of 1, 3, 6 and 8 in. on ultrasonic spot welds found the 3-in. radius to produce the most satisfactory weld.[1] Tip radii govern the weld areas and the amount of deformation of the material being welded. Small radii tend to deform severely the metal beneath them and to produce small bonds; in the case of weldments made in some heat-resisting alloys, they contributed to cracking of the refractory metal being welded. Some initial welds made using a flat weld tip with a large surface area were extremely weak and had no single welded area, but numerous tiny welds over the surface. As the tip radius is increased, the clamping force will become distributed over a larger area which may promote the welding of some materials, especially thin gages. A flat anvil surface was used consistently throughout these studies.

Also shown in Fig. 15 is the effect of roughening the weld tip on weld strength for varying tip displacement, indicating no significant change in weld strength for a given tip displacement. When the tip is roughened, energy losses at the tip-weldment interface are lessened because the roughened weld tip prevents sliding at the interface. If the anvil also had been roughened, it might have prevented slippage

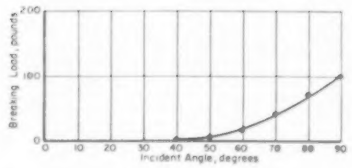
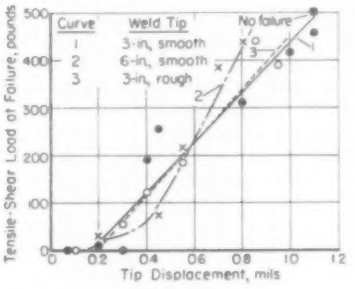


Fig. 14—Relationship between breaking load and incident angle of weld tip. Copper-Monel welds at 100-lb clamping force and 2-sec weld time. Displacement of 1.1-mil at a 90-deg angle of incidence

at the anvil-weldment interface allowing a high efficiency in coupling the energy into the weldment. Because sliding at the tip-weldment interface was prevented by roughening the tip surface, the aluminum did not weld to the tip, nor was there any noticeable transfer of aluminum to the weld tip. When smooth weld-tip surfaces were employed, aluminum, as well as other materials studied, welded to the tip, and material was transferred to the weld tip. When welding heat-resistant materials, the welds produced at the tip-weldment or anvil-weldment interface would be strong enough to pull material from the tip or anvil. The degree of welding to the tip and anvil was lessened by slightly roughening their surfaces with 240-grit emery paper.

The effect of roughening the anvil surface on weld strength was not studied. However, studies of interfacial temperature generated during welding indicated a slight increase in temperature when a roughened anvil was used

Monel welding tips were used during this study because Monel was found to have low energy



Sheet thickness: 0.040 in.
Clamping force: 200 lb
Weld tip: Type 5 (see graph)
Cleaning: degrease
Weld time: 4 sec
Anvil: Type 3, flat radius

Fig. 15—Variation in weld strength with tip displacement for two tip radii and two degrees of tip surface roughness for ultrasonic spot welds in 1100-H18 aluminum

losses and possesses good fatigue properties. Weld tips machined from carbon drill rod also were investigated. They produced extremely weak welds, indicating poor coupling of energy into the weldment, possibly due to a low coefficient of friction at the tip-work interface. Mild-steel and carbon drill rod were used successfully as anvil materials for welding the materials under investigation. A few welds were made using an experimental tip made of alumina in conjunction with an alumina anvil insert. Welds reached higher temperatures and had greater strength when made with alumina tips and anvils. However, the life of these inserts was short due to fatigue under the high shear and thermal forces encountered during a welding cycle. Glass and lavite also were investigated for use as a tip or anvil materials but they generally disintegrated when subjected to an ultrasonic-welding cycle. Indications are that welding tips and anvils should be made of materials having low thermal conductivity and high shear strength at elevated temperatures.

Effect of Material Variables

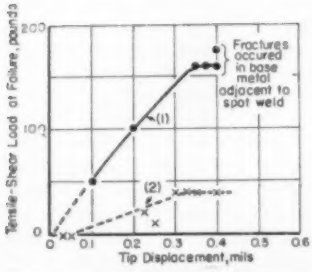
The material variables studied during this investigation were:

1. Surface cleanliness.
2. Material thickness.
3. Amount of cold work.

The presence of surface films is a deterrent to the bonding of metals, especially if the bonding takes place in the solid state as in pressure welding.[9-11] These films are generally oxides of the base metal but may be other compounds or consist of absorbed moisture or gases. A study was made to determine the effect of cleaning on ultrasonic welds in aluminum. Two preweld procedures were used for aluminum during this study. One consisted only of degreasing in trichloroethylene, the other removed the heavy-oxide film. The second procedure was as follows:

1. Degrease in trichloroethylene.
2. Dip in 5% NaOH solution at 150 to 160° F. for 30 sec.
3. Rinse in running water.
4. Dip in 50% HNO_3 solution for 30 sec.
5. Rinse in distilled water.

Results of this study made using 0.040-in.-thick annealed aluminum are shown graphically in Fig. 9. As can be seen, only a slight improvement in weld strength, if any, at a given tip displacement was found for aluminum cleaned by the



Curve No.	Material	Sheet Thickness in.	Cleaning	Clamping Force, lbs	Weld Time sec	Weld Tip Type	Weld Tip Radius in.	Anvil Type	Anvil Radius in.
1	Gold	0.015	degrease	200	1	1C	3	3	Flat
2	1100-H18 Al	0.016	$NaOH-HNO_3$	150	2	1C	3	3	Flat

Fig. 16—Variation in weld strength with tip displacement for ultrasonic spot welds in annealed gold and aluminum

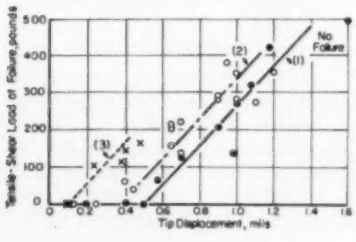
$NaOH-HNO_3$ method. No effect of cleaning was found for full-hard aluminum of the same thickness. No gross amount of oxides in the weld interface in either the cleaned or uncleaned aluminum were observed during metallographic examination of the welds. In some sections of ultrasonic welds made during this study, there appeared to be some inclusions in, or near, the interfaces which might have been surface oxides which were not moved out of the joint area. These inclusions constituted a very small percent of the bond area and apparently did not seriously affect weld strength. It is well known that the oxide film on aluminum can be broken up during pressure welding because of the great differences in mechanical properties between aluminum and its oxide.[10, 11] In ultrasonic welding, the breakup of this film may be accelerated by abrasion occurring due to relative movement between the surfaces being welded, thus achieving metal-to-metal contact in short periods of time with little deformation of the metal being welded. The oscillatory motion also may aid in removing the broken-up oxide from the interface. The black residue surrounding the bond in many ultrasonic welds in aluminum may be a very finely broken-up aluminum oxide.

The appearance of the interface of fractured aluminum welds was different for welds in cleaned aluminum than for welds in uncleaned aluminum. The bonded area was nearly circular when cleaned aluminum was welded with little or no area outside the weld affected. Welds in unclean aluminum were not restricted to a circular area. The weld area was annular in shape which indicates welding took place in the periphery of the original contact area due to slippage. Perhaps the oxide film was not broken up and removed in the central portion of the weld area and thus prevented welding in this area.

Welding studies made with gold showed nearly linear relationships between joint strength and the welding parameters, tip displacement, clamping force and weld time. Ultrasonic spot welds possessing good strength also could be made in gold at low tip displacement and low weld times. Figure 16 shows the variations in weld strength with tip displacement for annealed gold and aluminum sheet. It can be seen that aluminum did not bond as readily or achieve full strength in the same range as did the gold. The mechanical properties of these two metals are similar. The greatest difference is the presence of the hard, tenacious oxide film on aluminum. The lack of an oxide film on gold may explain the consistency of results and ease of bonding when welding gold by the ultrasonic-welding process.

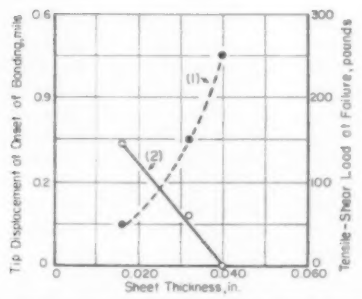
Investigations were made to study the effect of material thickness on ultrasonic welds in aluminum. The effect of tip displacement on the strength of ultrasonic welds in 0.016-, 0.032- and 0.040-in.-thick 1100-H18 aluminum is shown in Fig. 17. This shows that equivalent weld strength was obtained at lower tip displacements in the thinner material. Tip displacements exceeding 0.5 mil were not studied for the 0.016-in.-thick aluminum. In welds made with this displacement, failures occurred in the base metal during tensile testing indicating maximum usable strength had been achieved. Figure 18 was plotted from the data in Fig. 17. Shown is the effect of sheet thickness on the tip displacement at the onset of bonding and the strength of welds made at the same tip displacements. Similar relationships probably exist for other weldments studied. It is reasonable that as thickness is increased (i.e., the distance through which the vibrations must be transmitted) the amount of energy available at the interface is lowered. For a given tip displacement, there is a maximum sheet thickness at which all the vibrational motion transmitted to the work from the weld tip is absorbed by elastic and, possibly, plastic deformation of the sheet directly under the weld tip. Another effect of sheet thickness is the distribution of pressure beneath the tip. As thickness increases, the clamping pressure becomes distributed over larger areas of contact. increasing the area over which the clamping force is distributed means higher power inputs are required to produce a bond.

A study was made of the effect of prior cold work on ultrasonic welds in 0.016-in.-thick aluminum sheet. The effect of cold work was studied by varying tip displacement at constant clamping pressure and weld time while welding various tempers of the aluminum sheet. The degree of cold work is expressed as microhardness to assist in plotting the data obtained. Figure 19 shows the relationship between the tip displacement at the onset of bonding and microhardness of the base metal. It was found to be extremely difficult to produce welds in the 1100-O aluminum of this thickness. This material was apparently so soft that the tip motion was completely dissipated in gross motion of the weldment without producing a strong bond. It was noted during welding that the vibratory energy was coupled through the weldment into the anvil. The hard oxide also might tend to bury itself in the extremely soft aluminum and thus prevent the production of strong bonds. Other investigators have experienced difficulties in the welding of very soft aluminum as well as the very hard.[5] No difficulty, however, was encountered in welding the 0.040-in.-thick 1100-O aluminum. Another



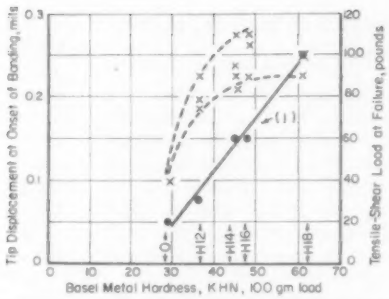
Curve No.	Material	Sheet Thickness in.	Cleaning	Clamping Force lb	Weld Time sec	Weld Tip Type	Weld Tip Radius in.	Anvil Type	Anvil Radius in.
1	1100-H18 Al	0.040	$NaOH-HNO_3$	200	4	1C	3	3	Flat
2	1100-H18 Al	0.032	$NaOH-HNO_3$	200	4	1C	3	3	Flat
3	1100-H18 Al	0.016	$NaOH-HNO_3$	200	4	1C	3	3	Flat

Fig. 17—Variation in weld strength with tip displacement, for three sheet thicknesses for ultrasonic spot welds in aluminum



Curve No.	Relationship	Material	Cleaning	Tip Displacement, mils	Clamping Force lbs	Weld Time sec	Weld Tip Type	Weld Tip Radius in.	Anvil Type	Anvil Radius in.
1	Sheet Thickness vs Tip Displacement	100 H8 Al	NaOH, HNO_3	Variable	200	4	1C	3	3	Flat
2	Sheet Thickness vs Strength	100 H8 Al	NaOH HNO_3	0.4	200	4	1C	3	3	Flat

Fig. 18—Variation in displacement at onset of bonding with sheet thickness and variation in weld strength with sheet thickness for ultrasonic spot welds in aluminum



Curve No.	Relationship	Material	Sheet Thickness in.	Cleaning	Tip Displacement, mils	Clamping Force lbs	Weld Time sec	Weld Tip Type	Weld Tip Radius in.	Anvil Type	Anvil Radius in.
1	Hardness vs Tip Displacement	1100 Al	0.016	NaOH HNO_3	Variable	100	2	1C	3	3	Flat
2	Hardness vs Strength	1100 Al	0.016	NaOH HNO_3	0.35-0.5	150	2	1C	3	3	Flat

Fig. 19—Variation in tip displacement at onset of bonding and variation in weld strength with degree of prior cold work for ultrasonic spot welds in aluminum

phenomenon which was noted in studying metallographic sections of welds made in various tempers was that the extent of the turbulence at the interface increased with increasing prior cold work.

Effect of Excessive Weld Time

Figure 20 shows a metallographic section cut parallel to the direction of motion and through the center of a Monel sphere-copper plate weld. This weld was made using a 2-sec weld time under a clamping force of 100 lb and a displacement of 1.3 mils. Breaking loads for welds under similar conditions ranged from 120 to 140 lb. From Fig. 4, it is apparent that the weld time used in making this weld was not in the time range where breaking load was nearly proportional to time. A weld made under these conditions was selected for study to determine what possible effects might have occurred to cause lowering of the breaking load when the weld times exceeded the time range where breaking load was proportional to weld time.

The cracking of both copper and Monel near the edge of the weld is probably the prime cause of lower breaking loads. The mechanism leading to this cracking might be the continual imbedding of the Monel sphere in the copper. Under sliding conditions, a molten film might have been produced and forced outward to increase the contact area to accommodate the clamping force. When the sphere had imbedded itself to a depth where contact area was sufficient to resist the force, it is possible that only cyclic sliding took place near the edge of the weld area. This would reduce the temperature near the edge resulting in film freezing and the formation of a metallurgical bond. With continual excitation, the bond was broken and remade with each cycle of motion leading to gross cracking and cold working of the weld materials.

Figure 21 shows a portion of the weld interface near the center of the weld area. The left side of the interface appears to have experienced a sliding action over a molten film of copper since no sublayer of copper appears to be worked. The right side of the interface shows where a weld may have been made and broken in shear as indicated by the cold-worked sublayer of copper. This make and break of a welded area might be analogous to slipstick action encountered during the sliding of two surfaces.

Figure 22 shows portions of the weld midway between the center of the weld area and its periphery. Here the copper is welded to Monel but is divorced from the copper bar along a line somewhat defining the thickness of the layer of copper cold worked during the welding cycle.

Figure 23 shows a crack in the Monel sphere approximately three-fourths of the way from the center of the contacted area to its edge. Copper was forced into the crack, tending to open it up and causing the Monel to imbed into the copper. Such metal flow may be indicative of the mechanism leading to the turbulence encountered at times when metals are ultrasonically welded.

During normal ultrasonic welding, the interfacial contact area increases rapidly during the initial portion of the weld cycle reaching an equilibrium value dependent upon clamping pressure, tip radius and surface and tip displacement. Once the equilibrium value for the contact area is achieved, it is reasonable to believe that the bond is formed and energy is no longer absorbed at the interface. If the weld time exceeds this interval, vibration may cause slippage between the workpiece and anvil and/or workpiece and weld tip, which accounts for the welding of the work to the tip and anvil at longer weld times. If slippage did not occur at one or both of these interfaces, the bond could be weakened due to excessive cold work and cyclic stressing of the weldment. As discussed in another paper,[6] severe cracking does occur in many joints in heat-resistant materials at high tip displacements and long weld times.

Fig. 20—Macrograph of ultrasonic weld between Monel and copper. Section parallel to motion through center of weld. (1.3-mil tip displacement. 100-lb clamping force, 2-sec weld time, Type 1B, 5/16-in.-radius tip.) 5 HNO_3, lactic. X 37. (Reduced by 1/3 upon reproduction)

Theoretical Analysis of Sphere–Plate Welds

When a sphere is vibrated under a clamping force on a softer yielding plate, the actual contact area between the two will vary during each cycle of vibration. The area contacted by the sphere will increase with each cycle of vibration until it is great enough to support the clamping force without further yielding. In welding, the contact area is directly related to the strength of a weld and is a function of the sphere radius, clamping force, weld time, relative displacement, yield strength of the materials and their rate of yield. For any combination of welding conditions, there is a maximum value of contact area. Figures 11 through 14 indicate the general relationships to be expected when the welding-condition time, displacement and clamping force are varied.

Fig. 21—Micrograph of the central portion of the interface of Monel-copper weld. 5 HNO_3,30 lactic. X 500

Fig. 22—Micrograph of interface midway between center and edge of Monel-copper weld. 5 HNO_3, 30 lactic. × 500

Fig. 23—Micrograph of interface about three quarters the distance from center to edge of Monel-copper weld. 5 HNO_3 30 lactic. × 500

Experimental data for welding a Monel sphere to a copper plate show an optimum value of a welding variable for producing a weld with a maximum breaking load when all other variables are held constant. Thus, the fact that actual contact area approaches a maximum and that maximum breaking loads are reached just before maximum areas are reached, would indicate that continuous yielding of material in the weld area must occur before a bond is formed. If not, welding might possibly occur during the early stages of an ultrasonic-welding cycle. Such "early" welds would have to fail by shearing along the interface, or they might result in cracking at the edge of the weld area where the resultant tension component of the ultrasonic shear and clamping force would be highest. The crack would then relieve the shear force tending to maintain weld area constant. Weld strength would remain constant or would diminish depending on the effect of continuing stress on the crack.

The larger the radius of the sphere, the less deformation or imbedding of the sphere is required under a given load to provide sufficient contact between the sphere and plate to prevent further yielding. With each cycle of motion, the sphere imbeds itself some incremental depth. Plate material is displaced or plowed, forming a ridge along the leading edge of the contact area which moves in the direction of motion. The perimeter of this edge is crescent shaped, with a maximum buildup of material at the center of the crescent where the pressure is the greatest and a minimum or no buildup at the ends of the crescent. The degree of buildup increases with a decrease of sphere radius.

An indication of plowing and yielding occurring during an ultrasonic-welding cycle was given when a hard sphere was vibrated under load on lucite. Concentric rings of deformed lucite were observed on the surface of the cavity produced where the sphere imbedded itself. Due to the plasticity of the lucite at the temperature produced, it is believed that a deformation ring was produced during a cycle of motion, building up and permanently setting before the next cycle. During the next cycle, the sphere imbedded itself sufficiently that the previous deformation ring was acted upon elastically, thus leaving a perma-

nent indication of how yielding occurred. At the base of the lucite cavity where the sphere was apparently in contact under yielding pressures, an elliptical smooth or abraded surface was noted. An abraded surface was noted if the clamping force was removed before vibrations ceased. The similarity in appearance between the cavity produced in lucite and the weld area of an ultrasonic weld would indicate that during welding with spherical welding tips a central region, generally bounded by two intersecting crescents, experiences shear continuously and that the remaining weld area experiences only cyclic shear or yielding, and/or elastic deformation. The oxide generally observed about the periphery of a weld occurs in the area affected by cyclic shear or elastic deformation. This oxide may be formed by the frictional heating and periodic exposure of clean metal to the atmosphere, resulting in an oxide layer which may be abraded free during slipping portions of a displacement cycle. The turbulence often observed in ultrasonic welds may be ascribed to the crescent-shaped buildup of deformed material during each cycle causing the opposing surface to yield to the buildup. The general shape of the expected buildup and that of the turbulent volume in a weld observed in this work and work by other investigators[1-5] seems to substantiate this suggested mechanism.

Oftentimes, after ultrasonic welds between Monel and copper had been broken, cracks were visible in the copper plate at the edge of, or within, the weld area. These cracks were generally arced on the surface in the direction of the weld-tip displacement. The photomicrograph, Fig. 23, of a copper-Monel weld shows that such cracking occurred before this weld was completed. The weld area continued to grow after cracking of the Monel since copper was forced into the crack. This also suggests another mechanism which might occur during ultrasonic welding which would produce turbulence in a weld.

Another factor influencing the maximum safe weld area, and hence weld strength, would be the radius of the spherical welding tip. Tension forces higher than the strength of the material acting at the edge of a weld area would be approached more rapidly with smaller weld-tip radii. A deeper penetration of the sphere would be required for a smaller radius sphere to produce a given weld area. Hence, the component of stress normal to displacement of the weld tip would increase more rapidly, leading to earlier tensile failure.

What the basic mechanism of bonding is during an ultrasonic-welding cycle has not been definitely established. Two mechanisms are suggested, namely, pressure welding and fusion welding. It is conceivable that both mechanisms may occur separately or simultaneously. The results of experiments have shown that a minimum displacement is required before welding can occur. It is believed that this minimum value represents the motion required to overcome the compliance of the components being welded and/or the welding assembly. Displacement below this minimum could not lead to energy dissipation at the interface of sufficient magnitude to produce high temperatures which were found to be directly related to weld strength. A resultant conclusion is that complete sliding or, at least, some slippage between interfaces is required. With sliding between interfaces, the oxides may be effectively broken up, as the base material yields, and removed from the surface during each cycle of motion. This oxide removal would provide intimate metal-to-metal contact, which under proper temperature and pressure conditions could produce a weld.

Experimental work performed by Johnson[12] on surface interaction between elastically loaded bodies under tangential forces has correlated with Mindlin's theory on the mechanism of friction between two elastic spheres.[13] The experimental arrangement used by Johnson (vibrating sphere on a plane) is analogous to the arrangement used to weld a Monel sphere to a bar of copper, except that relatively low energy was used in Johnson's work and elastic limits were not exceeded. The mechanisms examined theoretically by Mindlin and investigated experimentally by Johnson might be considered as a mechanism occurring in ultrasonic welding at the lower limits of welding conditions.

Mindlin has examined the compliance of two perfectly elastic spheres of similar materials in contact under a normal and tangential force. He assumed that the traction at all contact points cannot exceed the product of a constant coefficient of friction and the normal pressure. To satisfy this condition, the surfaces must be assumed to slip relative to each other over an annulus, while no slip occurs over the contact area within the annulus.* Johnson has demonstrated experimentally the relation between the annulus produced by fretting due to slippage between a sphere and a plane. The occurrence of annular patterns in ultrasonic welds seems to indicate that, as in the case of fretting, slippage as well as sliding plays a part in ultrasonic welding.

Mindlin[13] also examined the effect of an alternating shear force on slippage between spheres. While the shear force is increasing to a peak value, some nonelastic slip would occur on the annulus. If the shear force is decreased, counter slip must begin at the boundary of the contact circle. He shows that a complete cycle of shear force produced a closed symmetrical hysteresis loop, the area of which determines the energy lost per cycle at the contact area. Under sliding conditions, the energy dissipated from slipping would be,

$$E_1 = 0.8\mu_s N X_s$$

where

μ_s = coefficient of static friction.
N = clamping force.
X_s = minimum displacement required for sliding.

It is thought that, during ultrasonic welding of two masses, yielding of asperities or bulk material at the contact area occurs but that the pressure distribution over the area causes cyclic slippage similar to that encountered in an elastic sphere-plane system. This would be particularly true when spherical welding tips are used. The energy dissipated at contact surfaces where sliding does not occur in a cycle may be considered as a factor influencing ultrasonic welding, particularly in producing an oxide layer about the periphery of the weld.

Perhaps the greatest source of energy at contact surfaces during ultrasonic welding is due to complete sliding between surfaces. The energy dissipated per sliding cycle can be expressed as

$$E_2 = 2\mu_K N X_t \qquad (1)$$

where

μ_K = coefficient of kinetic friction.
N = weld clamping force.
X_t = relative displacement between surfaces.

If both sliding and slipping occur during a vibrational cycle, then the total energy dissipated per second of weld time at the contacting area is

$$E_T = (E_1 + E_2)f \qquad (2)$$

* The term "slip" as used in this paper means movement over an annular area. Sliding means relative motion over the entire contact surface.

where f = frequency of motion, cycles per second.

A massive ultrasonic-welding tip having a spherical surface in contact with a massive anvil having a flat surface would be a simple welding system. The heat developed at the contact area of such a system when the tip is excited will flow into the tip and the anvil. If it can be assumed that steady-state thermal conditions are reached during a weld with such a system, the thermal conductance of the system can be expressed as

$$Q = KT \qquad (3)$$

where

Z = heat flow per second.
K = thermal conductance.
T = temperature drop.

For this simple welding system, the thermal conductance from the contact area into the tip and anvil may be written as $4a(K_1 + K_2)$ where "a" is the radius of the contact area and K_1 and K_2 are the respective thermal conductivities of the weld tip and anvil materials.[8] Assuming thermal equilibrium, thermal conditions can be expressed as

$$T - T_0 = \frac{Qt}{4a(K_1 + K_2)} \qquad (4)$$

where

T = temperature at contact surface.
T_0 = ambient temperature.
Q_t = heat generated at contact area.

The heat generated at the contact area is equal to the total energy dissipated E_t/J where J is the mechanical equivalent of heat. Assuming that continuous plowing does not occur during ultrasonic welding, that the physical and mechanical properties of the materials do not change with temperature, and that sliding takes place, it can be written

$$T - T_0 = \frac{(2\mu_K X_t + 0.8\mu_s X_s)}{4Ja(K_1 + K_2)} \qquad (4a)$$

If the contact radius is assumed, a, under yielding conditions can be expressed as[8]

$$a = \left(\frac{N}{3\pi Y}\right)^{1/2}$$

where Y = yield strength; then

$$T - T_0 = f(3YN)^{1/2} \frac{(2\mu_s X_t + 0.8\mu_K X_s)}{4J(K_1 + K_2)} \qquad (4b)$$

Inserting the appropriate physical and mechanical constants for a copper anvil and a Monel weld tip in equations, assuming μ_s to be 1.5 and considering a clamping load of 100 lb, it is found that a tip displacement of approximately 0.5 mil would be required to produce sliding between anvil and tip. Under these conditions, contact pressures of 2×10^5 psi would exist. Using this value of minimum displacement for sliding in eq 4b and assuming a displacement of 1 mil, the calculated temperatures at the Monel–copper junction would approach 500° C (932° F). Under such conditions of temperature and contact pressure, a pressure weld between the copper and Monel might occur. Data from Tylecote[9] for pressure welding copper and nickel support this supposition.

If one no longer considers the copper of the simple welding system as massive but as a relatively thin sheet clamped to a steel anvil, the system becomes similar to the system used in these experiments. In such a system, the thermal conductivity of the steel anvil governs the heat conducted from the weld zone and provides a system whose thermal conductivity is approximately ten times lower than in the simple system considered above. This would indicate that temperatures in the range of 5160° C (9320° F) could occur at the copper–Monel interface for a total displacement of 1 mil. However, it has been shown that temperatures due to sliding friction do not exceed the melting point of the lowest melting metal.[8] Under such conditions, ultrasonic welds can be considered to be produced by a fusion process.

Under conditions of normal elastic loading where displacements are much greater than those required to overcome the elastic forces resisting plowing of the weld materials and compliance of the welding assembly, it is conceivable that sufficient energy could be dissipated to produce fusion welds. Under yielding conditions with large displacements, it is possible that the area of the welding tip and bar continually in contact could dissipate sufficient energy to raise temperatures to the melting point. The areas which are in contact intermittently, i.e., only at full excursions of the weld tip, could weld under high pressure and temperature but the weld also would be sheared with each cycle. This could account for the working of material near a weld interface. The metallographic section of a copper–Monel weld showed that there are areas of contact where little or no worked copper can be seen which might be ascribed to low shear force due to the presence of a molten film. As one progresses from these locations along the direction of motion, the worked copper layer becomes pronounced and progressively thicker, indicating that high shear forces were at play. These observations appear to substantiate the idea that both pressure welding (solid state) and fusion welding may occur simultaneously. The possibility of pressure welding *per se* also can be envisioned if the displacement amplitude is too small to generate sufficient heat to reach the melting point of the weld material, but sufficiently large to raise the temperature to a value conducive to pressure welding under a yielding clamping load.

Breaking load of copper–Monel welds appeared to be directly proportional to the temperature measured at the weld interface during a welding cycle. The fact that weld strength still varied with time after constant temperature was reached would indicate that conditions at the weld zone were approaching equilibrium when maximum temperature was reached; i.e., continuous yielding was stopping and elastic loading was beginning to take place throughout a cycle of motion. At the onset of equilibrium, the contact area would be near maximum, giving maximum weld strength. Shortly after equilibrium, the sphere would have imbedded itself to a point where the tension component of the shearing and clamping force was great enough to fatigue the copper at the periphery of the contact area reducing the strength of the weld, or oxidation of the copper surface intermittently in contact with the Monel would take place reducing the effective welded area. Welds produced in a vacuum or in an inert atmosphere should show what relation oxidation during welding has on the ultimate strength of ultrasonic welds.

If one can assume, from the limited data obtained, that the breaking load of a weld is proportional to the temperature developed during a welding cycle, one can get an indication of how the physical and mechanical properties of the weld materials, the welding arrangement and the welding variables are related to weld strength from eq 4a. These relationships show some degree of correlation with experimental data for weld strengths below the ultimate strength attainable. The deviation from linear relationships may be ascribed to the variation of physical and mechanical properties of materials with temperature.

Conclusions from Theoretical Analysis

Further studies are required to establish the law, or laws, governing

ultrasonic welding; however, it is apparent that the strength of an ultrasonic weld can be controlled by varying either the weld time, clamping force, relative displacement between the two members being welded, or the pressure distribution between members as governed by the contacting surface coupling vibration to one of the members. It is indicated that compliance of members being welded and that of the welder assembly determine the absolute minimum welding-tip displacement required to initiate sliding between members and thus welding. If two sheets of material are taken as an example and the ductility of the sheets are such that, under yielding force, the area under the welding tip alone can be assumed to shear, the minimum displacements would be:

$$X_s = \frac{S}{G}(t_1 + t_2)$$

where

t = thickness of plate.
S = shear strength of plate interface.
G = shear rigidity of the plate material.

As the thickness of the members increases, the clamping force at their interfaces cannot be assumed to be distributed locally below the welding tip. Under such conditions, the minimum displacement for sliding decreases due to the greater rigidity of the member, but the contact area increases requiring larger relative displacements or greater clamping forces between members to produce the temperatures required for welding. If the member to be excited ultrasonically is massive or noncompliant, exceptionally high welding forces would be required at the welding tip to produce sliding. These forces could result in local stressing near the tip beyond the point of fatigue before a weld could be produced. If the members are relatively massive but have a mechanical resonance near that of the welding frequency, high stress some distance from the weld could result in fatigue failures of the material. During the welding of some aluminum and copper plates, this occurrence was noted.

One limitation for ultrasonic welding is the ability to couple ultrasonic motion to one of the members being welded. Indications are that the pressure distribution at the interfaces being welded is a factor influencing welding. If a weld tip and anvil design required to give proper clamping force distribution is such that the frictional and plowing forces between them and the weld materials are less than those between members being welded, sliding will occur at the anvil and tip with no energy being coupled to the desired weld area.

Specific laws regarding the effects of changing welding conditions are not readily apparent. Such laws could be obtained for a given material, but predominant material effects overshadow the effects of welding conditions when changing from a material such as aluminum to materials such as titanium or stainless steel. Material properties such as the melting point, elastic modulus, yield, ultimate, and shear strengths, surface condition and ductility appear to influence ultrasonic welding. To further complicate understanding of the fundamentals of the process, these material properties probably vary from the room or ambient temperature value to the value at temperatures at, or approaching, the melting point. The use of such techniques as weldment preheating may be desirable mainly to alter material properties at the start of welding instead of as an auxiliary heat source as it has been used. As an example, molybdenum at room temperature is below the transition temperature for ductile-to-brittle behavior under certain types of loading. Increasing the ambient temperature above these transition temperatures might eliminate such problems as cracking noted in molybdenum ultrasonic welds.

It may be tentatively concluded that materials which can be pressure or fusion welded can be ultrasonically welded. However, the mechanical properties of the materials may limit the practical application of ultrasonic techniques. If the local ultrasonic force required to produce interfacial temperatures conducive to pressure or fusion welding exceeds the fatigue limits of a material, ultrasonic welding *per se* would obviously be of little value.

Acknowledgment

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RESEARCH NEWS

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for the Inspection of Ship Welds. E. L. Criscuolo, D. P. Case and D. Polansky, Naval Ordnance Laboratory. Feb. 1958. 61 pages. (Order PB 161324 from OTS, U. S. Department of Commerce, Washington 25, D. C., $1.75.) Isotopes of thulium 170, cesium 137, cobalt 60 and iridium 192 were explored to discover the best nondestructive, radiographic technique for inspecting $^1/_2$- to 2-in. steel plate for ship hulls.

Preliminary Studies of Brittle Fracture Propagation in Structural Steel. W. J. Hall, W. G. Godden and O. A. Fettahlioglu, University of Illinois, for Bureau of Ships, U. S. Navy. May 1958. 90 pages. (Order PB 161325 from OTS, U. S. Department of Commerce, Washington 25, D. C., $2.25.) This report covers research to measure by cathode-ray oscillograph the crack speed and strain distribution in mild steel hull plate.

Weldability of Aluminum Casting Alloys with 5086 Wrought Aluminum Alloy

In producing a ballistic missile, the joining of cast attachments to the thin wrought aluminum-alloy skin must be carefully considered

BY M. S. ORYSH AND I. G. BETZ

SYNOPSIS. The Pitman-Dunn Laboratories Group of Frankford Arsenal conducted an investigation for the Army Ballistic Missile Agency to determine the weldability of six cast aluminum alloys joined to 5086 wrought aluminum alloy. The cast alloys investigated were: Almag 35, Al – 7% Mg, 214, 356, 42B and Al – 7% Mg – 3% Zn.

It was found that, within the scope of this investigation, the cast alloys Almag 35, Al – 7% Mg and 214 could be satisfactorily welded to the 5086 material. When the casting was overmatched by the 5086 member, thereby forcing failure to occur in the casting, the material combinations having the highest ultimate joint strength included Almag 35, Al – 7% Mg and 214, in that order, with very little difference between the latter two. The joining of those casting–filler metal–5086 alloy combinations which contained both silicon and magnesium as major alloying elements was less likely to produce joints of reasonable strength and ductility due to the formation of magnesium silicide. Gross porosity was encountered in the weld when castings of the Al – 7% Mg – 3% Zn alloy were welded to 5086 alloy sheet. Because the gross porosity could not be readily overcome within the limits of this investigation, the joint strength of this particular combination was not determined.

The results of this study demonstrated that thin weldments were more apt to have a very poor joint efficiency due to lack of fusion if welded without a backing strip.

Introduction

The combination of moderate strength, weldability, good formability and excellent resistance to general and stress corrosion offered by the wrought 5086 aluminum alloy, promoted the use of this material for fabricating the skin of ballistic missiles. This alloy is particularly favorable from a welding standpoint since its strength in the annealed condition (which will exist in the heat-affected zone) exceeds that of other annealed aluminum alloys, such as 2024, 6061, and 5052. The 5086 alloy also has the advantage of having a slightly lower density than most other structural aluminum alloys, due to its high magnesium content.

In producing a missile, the joining of cast attachment to the thin 5086 structure must be considered. Not only must the casting have suitable properties for satisfying its service requirements, but it must be capable of being welded to 5086 sheet, approximately $^1/_8$ to $^1/_{16}$ in. in thickness, with reasonable strength and ductility.

The Pitman-Dunn Laboratories Group of Frankford Arsenal conducted an investigation for the Army Ballistic Missile Agency to evaluate cast aluminum alloys for maximum compatibility with the 5086 wrought aluminum alloy when joined by welding. It was requested that the screening of the cast aluminum alloys be based on the magnitude of the weld strength and ductility developed between the cast alloys and the wrought 5086 alloy sheet.

Materials

5086 Aluminum Alloy. The wrought 5086 aluminum alloy used in this investigation was in the form of sheet and plate having thicknesses of $^1/_{16}$ and $^3/_8$ in., respectively. The $^1/_{16}$-in. sheet was procured directly from the supplier in the H12 condition (strain-hardened, one-quarter hard). The $^3/_8$-in. plate was obtained in the laboratories by rolling 1-in. thick plate down to $^3/_8$ in. The temper of the rolled plate was found to approximate the H18 condition (strain-hardened, full-hard). The chemical analysis representing the sheet and plate is given in Table 1.

Table I—Chemical Analysis of 5086 Wrought Aluminum Alloy, Weight Percent

Mg	3.91
Si	0.05/0.15
Cu	<0.05
Fe	0.1/0.3
Mn	0.48
Zn	<0.05
Sn	<0.01
Pb	<0.01
Ni	<0.01
Cr	0.05/0.15
Ti	<0.02
Al	Rem.

Casting–Filler Metal Combinations. The casting–filler metal combinations selected for studying the weldability of casting alloys to the wrought 5086 materials were as follows:

Casting	Filler rod
Almag 35	5356
Al – 7% Mg	5356
Al – 7% Mg – 3% Zn-T6	5356
356-T7	5052
356-T7	4043
214	5356
214	5154
214	4043
42B-T6	4043
42B-T6	5052

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The opinions expressed by the authors do not necessarily reflect the opinions of the Ordnance Corps or the Department of the Army.

Table 2—Typical Chemical Analysis of Cast Aluminum Alloys, Weight Percent

Cast alloys	Mg	Si	Cu	Fe	Mn	Zn	Sn	Pb	Ni	Cr	Ti	Be	Na	Al
Almag 35	7.17	0.10	0.04	0.10	0.23	<0.05	<0.01	<0.02	<0.01	<0.01	0.16	0.006	...	Rem.
Al – 7% Mg – 3% Zn	7.2	<0.05	<0.02	<0.02	<0.01	3.1	N. D.	N. D.	N. D.	N. D.	0.1	0.004 0.005	...	Rem.
Al – 7% Mg	7.45	0.10	<0.03	0.14	<0.01	<0.05	<0.01	<0.02	<0.01	<0.01	0.01	...	...	Rem.
356	0.36	7.67	0.01	0.01	<0.01	N. D.	<0.01	<0.01	N. D.	N. D.	0.05 0.15	N. D.	...	Rem.
214	4.33	0.1 0.2	0.05 0.1	0.15 0.35	0.01	<0.05	<0.01	<0.01	<0.01	N. D.	<0.05	N. D.	...	Rem.
42B	0.47	8.29	0.05	0.18	0.01	<0.02	<0.01	<0.01	<0.01	<0.01	0.18	0.25	0.006	Rem.

In general, the basis for selecting the castings was their desirable properties and, with two exceptions, the likelihood of their being welded satisfactorily to the 5086 alloy. Since the high-silicon alloys (356 and 42B) possess some of the most favorable casting properties, these materials were included, even though it was realized that the weld properties might be influenced by the possible formation of magnesium silicide in the fusion zone. The typical chemical analyses of the castings are given in Table 2.

Since 356, 42B and the Al – 7% Mg – 3% Zn alloy castings derive their desirable mechanical properties from heat treatment and aging, it was expected that the temperature in the cast member adjacent to the weld due to the heat generated by welding would be sufficient to overage the heat-treated base material. The mechanical properties of the joint which included a heat-treated casting as one of the base members, therefore, would be lower due to the presence of this overaged region.

The choice of the filler metals to be used in this investigation was dictated by the composition of the two base members. In order to approach 100% joint efficiency and gain consistency in a weld, it is common practice to use a filler metal having a composition similar to that of the base metal. Also, in certain instances (such as in the aluminum-magnesium alloys) it is advisable to select filler metals having alloying additions that are slightly higher than those present in the base metal to compensate for any loss of these elements during deposition. Such practice promotes greater uniformity in composition across the joint. The composition of the weld metal becomes relatively independent of filler-metal dilution which otherwise could be an influential factor in controlling weld properties. Consequently, the 5356 aluminum alloy was selected as the filler metal for joining all the aluminum-magnesium castings to the wrought 5086 aluminum-alloy member.

Filler metal 5154 was also selected for welding the 214 casting to the 5086 member in order to determine whether any notable change in joint properties would occur if the magnesium in the filler wire were decreased. The magnesium in the 5154 filler material is approximately equal to the magnesium contained in each member of the 214–5086 (cast-to-wrought) combination. The 5356 filler alloy, however, contains more magnesium than the base members. In addition to the 5356 and 5154 filler alloys, it was decided to try the versatile silicon-bearing 4043 filler alloy to observe whether this popular filler material could be used to weld satisfactorily the 214 casting-to-wrought combination. It was recognized that an incompatible situation could develop due to the potential formation of magnesium silicide.

In view of the high-silicon content of the 356 alloy and the high magnesium content of the 5086 alloy, it was deciced to use the aluminum–5% silicon alloy (4043) and the aluminum–2.5% magnesium alloy (5052) as filler metals for welding these materials. Since the silicon content of 4043 and the magnesium content of 5052 are both lower than that which is present in 356 and 5086, respectively, it was assumed that either of these filler metals would tend to produce a magnesium or silicon gradient across the weld. With this gradient, it was believed that less magnesium silicide would form in the joint. For this reason, 4043 and 5052 filler rods were also selected for the 42B castings. Table 3 lists the chemical analyses of the various filler rods.

Procedure

The work accomplished during this investigation was divided into two main parts. The first part of the program involved the welding of $^1/_{16}$-in. thick 5086 wrought sheet to $^3/_{16}$-in. thick castings of the various alloys selected. These thicknesses were chosen in order to simulate a typical joint contour employed in

Table 3—Chemical Analysis of Aluminum Alloy Filler Rods, Weight Percent

Filler metals	Mg	Si	Cu	Fe	Mn	Zn	Sn	Pb	Ni	Cr	Ti	Be	Al
5356	5.33	0.05 0.15	<0.05	0.15 0.25	0.1 0.2	<0.05	<0.01	<0.02	<0.01	0.05 0.15	0.15 0.25	0.0003	Rem.
5052	2.61	0.05 0.15	<0.05	0.05 0.15	0.04	<0.05	<0.01	<0.02	<0.01	0.15 0.30	0.03	0.0005	Rem.
4043	<0.01	5.62	0.1 0.2	0.3 0.6	<0.03	<0.05	N. D.	N. D.	N. D.	N. D.	<0.03	N. D.	Rem.
5154	3.56	0.05 0.15	<0.05	0.15 0.25	<0.01	<0.05	<0.01	<0.02	<0.01	0.15	0.05 0.15	<0.0003	Rem.

Arrangement for welding cast to wrought aluminum alloys

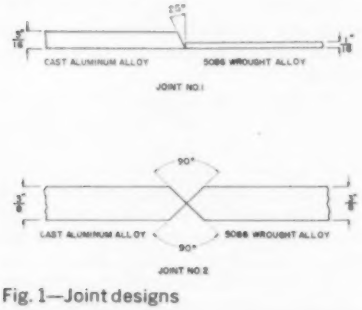

Fig. 1—Joint designs

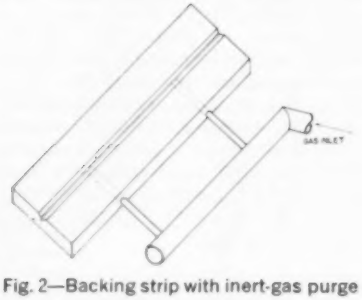

Fig. 2—Backing strip with inert-gas purge

missile fabrication. Castings less than $^3/_{16}$-in. thick were not practical to make, nor did it seem reasonable that thinner cast members would be used in actual practice. Transverse tensile specimens were removed from the weldments and tested.

The second portion of the work consisted of welding $^3/_8$-in. thick castings to $^3/_8$-in. thick 5086 wrought plate so that conventional transverse tensile specimens, having a uniform thickness, could be obtained. It was not practical to study such specimens in the first phase of the work due to the thinness of the sheet and castings. Transverse weld specimens, $^1/_4$-in. thick, were machined and tensile tested. The difficulties in the machining of thin transverse specimens dictated that the thickness of the specimens, from a practical standpoint, could not be less than $^1/_4$ in.

Discussion, in detail, of these procedures follows.

Casting: The dimensions of the castings which were made for the first phase of this investigation were 10 x 6 x $^3/_{16}$ in. These plates were made of all the cast alloys included in the program, with the exception of the 42B alloy (the 42B alloy was not included in the investigation until the work was well under way). Ingot materials obtained from commercial sources were used to produce castings of alloys 356, 214 and Almag 35. The castings of the Al – 7% Mg – 3% Zn alloy were prepared in the laboratory from aluminum, magnesium, zinc and the 218 aluminum alloy.

For the second phase of the investigation, the castings were $8^1/_4$ x 5 x $^3/_8$ in. The Al – 7% Mg – 3% Zn alloy was not included at this point since the welding of this casting to wrought 5086 sheet did not appear promising in the first phase of the work. The 42B alloy was cast from 42B ingot material with an addition of metallic sodium.

Heat treatment: Castings of the 42B and 356 alloys were solution-heat-treated for 16 hr at 1000° F, quenched in water (150 to 180° F), and artificially aged. The 42B alloy castings were aged for 4 hr at 330° F and the 356 alloy castings were aged for 2 hr at 400° F. Following the solution treatment, a 24-hr holding period was employed in heat treating the 356 alloy castings. The Al – 7% Mg – 3% Zn alloy castings were solution treated for 24-hr at 930° F, quenched in water (150 to 180° F), and aged for 30 min at 375° F.

All heat treating was done in a circulating air furnace and the solution and aging temperatures were controlled to ±5° F.

Experimental Practice

$^3/_{16}$-in. Thick Casting Welded to $^1/_{16}$-in. Thick 5086 Wrought Sheet

All wrought sheets were cleaned just before welding by immersing for 3 to 5 min in a nitric-hydrofluoric acid solution. After soaking, the sheets were washed with cold water. The $^3/_{16}$-in. thick castings were butt-welded to $^1/_{16}$-in. thick wrought sheet. The joint design was a single-bevel butt joint with a 25-deg bevel on the casting and no root opening (see Joint No. 1, Fig. 1). The gas tungsten-arc welding process was used. The filler rod was $^1/_{16}$ in. in diameter.

Table 4—Welding Procedures for $^3/_{16}$-in. Thick Castings Welded to $^1/_{16}$-in. Thick Wrought Sheet

	All castings (except Al – 7% Mg – 3% Zn) — Welded				Al – 7% Mg – 3% Zn
	One side			Both sides	
	Backing strip	Backing strip and inert-gas purge[a]	No backing strip	No backing strip	Welded one side, backing strip
Welding current, amp	195–205	195–205	145–155	125–135	140–200[b]
Welding voltage, v	23–25	23–25	23–25	23–25	23–25
Argon shielding-gas flow, ipm (liters/min)	3–5[c]	3–5[c]	3–5	3–5	5–15[d]
Tungsten-electrode diam, in.	$^3/_{32}$	$^3/_{32}$	$^3/_{32}$	$^3/_{32}$	$^3/_{32}$
Filler-rod diam, in.	$^1/_{16}$	$^1/_{16}$	$^1/_{16}$	$^1/_{16}$	$^1/_{16}$
Number of passes	1	1	1	2	1

[a] 1 to 2 lpm argon
[b] Welding current was increased by increments of 10 amp.
[c] For the 356-T7–4043–5086 combination, the argon shielding-gas flow was 6 to 8 ipm.
[d] Argon shielding-gas flow was increased by increments of 5 lpm.

With the exception of the Al – 7% Mg – 3% Zn and the 42B castings, two weldments each were prepared, representing the general welding procedure indicated below for each casting–filler metal–5086 combination:

(*a*) Welded on one side, using backing strip;
(*b*) Welded on one side, using backing strip and inert-gas (argon) purge (Fig. 2);
(*c*) Welded on one side, without backing strip;
(*d*) Welded on both sides, without backing strip.

The joints for (*a*), (*b*), and (*c*) above were welded in one pass. In welding both sides of the joint, as in (*d*) above, one weld pass was adequate for each side. All the welding data for the four techniques used are recorded in Table 4. Each weldment was X-rayed prior to machining into tensile-test specimens.

Four transverse-weld tensile-test specimens were cut from each weldment and machined to conform to the dimensions shown in Fig. 3.

In view of the possibility of fracture occurring in the weld region, five thickness measurements were made in each of six locations between the casting and the sheet. In this manner, it was believed that the cross-sectional area at the point of fracture could be established with fair accuracy.

In exploring the weldability of the Al – 7% Mg – 3% Zn alloy, work was initiated by attempting to weld on one side, using a backing strip (procedure (*a*)). The welding conditions, i.e., amperage, voltage, etc., were generally similar to those used for welding the other combinations (Table 4). As is discussed later in this report, gross porosity was encountered; this could not be readily overcome, although variations in the welding procedure were tried to a limited extent. Additional castings were also made and tried without success. Since the other combinations appeared to be more promising at this point, no further work was done with this alloy.

3/8-in. Thick Casting Welded to 3/8-in. Thick 5086 Wrought Plate

The castings and plates used for this phase of the investigation were 8 1/4 x 5 x 3/8 in. All casting–filler metal–5086 combinations were included, except for the Al – 7% Mg – 3% Zn casting. The joint design was a 90-deg double-vee butt joint with no root opening (see Joint No. 2, Fig. 1). Both sides of the plates and castings were cleaned by wire brushing for a distance approximately 1/2 in. back from the beveled edge. These joints were welded, employing the gas tungsten-arc welding process, using 1/16-in. diam filler rod. Two passes were deposited in each groove. Table 5 records the welding data for these specimens.

The weldments were sectioned for the removal of transverse-weld tensile-test specimens, as shown in Fig. 4. Those specimens which were to be used for tensile tests were machined to the dimensions 10 x 3/4 x 1/4 in., and X-rayed. X-raying was done at this time rather than immediately after welding in order to eliminate extraneous areas, such as the reinforcement. Thus, it was believed that a clearer impression of the quality of the joint to be tested could be obtained. The specimens were finished to conform to Fig. F2 of Federal Test Method Standard No. 151 by machining a reduced section.

Results and Discussion

3/16-in. Thick Castings Welded to 1/16-in. Thick 5086 Wrought Sheet

Al–7% Mg–3% Zn Alloy. The preliminary weldments made by joining the 3/16-in. thick Al–7% Mg–3% Zn alloy casting to the 1/16-in. thick 5086 wrought sheet, using 5356 alloy as the filler metal, disclosed large areas of porosity at the weld face. A section was taken from the weld and examined. It was found that gross porosity was concentrated along the edge of the Al–7% Mg–3% Zn alloy casting. The amount of porosity found in the weld greatly exceeded that found

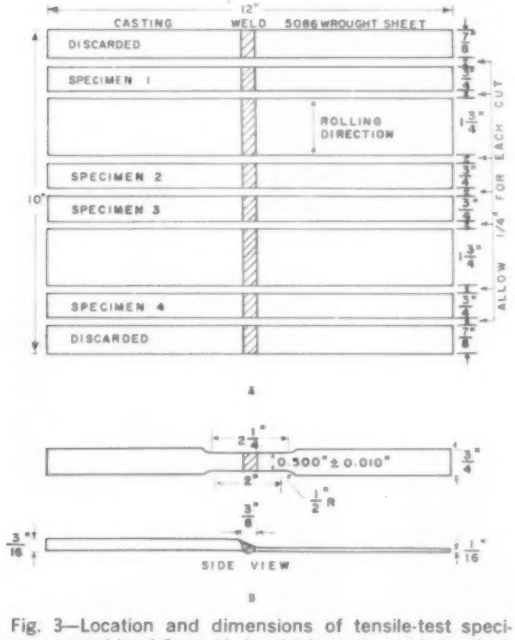

Fig. 3—Location and dimensions of tensile-test specimens machined from 3/16-in. thick castings–1/16-in. thick 5086 wrought-alloy weldments. A—Sectioned weldments. B—Transverse-weld tensile-test specimen

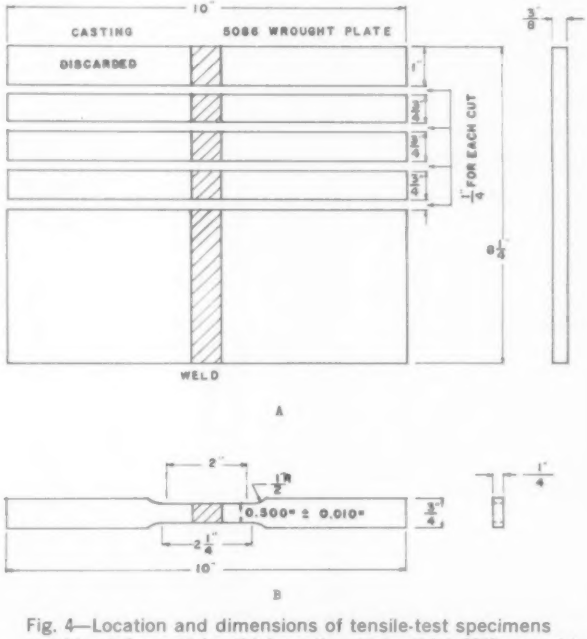

Fig. 4—Location and dimensions of tensile-test specimens machined from 3/8-in. thick casting–3/8-in. thick 5086 wrought-alloy weldments. A—Sectioned weldments. B—Transverse-weld tensile-test specimen

Table 5—Welding Procedure of $^3/_8$-in. Thick Castings Welded to $^3/_8$-in. Thick 5086 Wrought Alloy

Welding current, amp	195–205
Welding voltage, v	23–25
Argon shielding-gas flow, lpm	4–6
Tungsten-electrode diam, in.	$^3/_{16}$
Filler-rod diam, in.	$^3/_{32}$
Number of passes	4

in any of the other combinations. Several commercial aluminum-alloy filler rods of different chemical compositions were tried without success. After each trial, the weld was examined and was found to contain gross porosity.

Further tests were conducted by welding two cast plates together with 5356 filler wire and without any filler wire. In each weldment, gross porosity again was found in the weld zone. The presence of gross porosity in the joint when two Al–7% Mg–3% Zn alloy castings were welded together seemed to confirm that the casting was the principal cause of porosity. It was recognized that hydrogen entrapped in the casting and/or zinc vaporization from the melted portion of the casting during the welding operation could be responsible for the porosity noted in these welds.

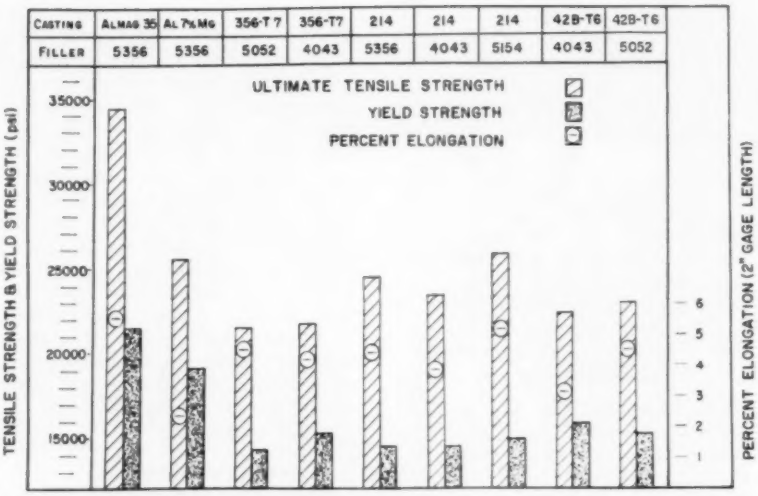

Fig. 5—Average tensile data on transverse-weld specimens removed from $^3/_8$-in. thick castings joined to $^3/_8$-in. thick 5086 wrought alloy; each weldment was machined to $^1/_4$-in. thickness before the specimens were removed

Radiographic examination: An examination of the radiographs re-

Table 6—Ultimate Tensile Results of Transverse Weld Specimens Removed from $^3/_{16}$-in. Thick Castings Joined to $^1/_{16}$-in. Thick 5086 Wrought Alloy. Each Joint Was Welded on One Side with the Use of a Backing Strip

Weldment	Ultimate tensile load, lb	Utimate tensile strength, psi	Fracture location[a]	Weldment	Ultimate tensile load, lb	Ultimate tensile strength, psi	Fracture location[a]
Almag 35–5356–5086	1265	40,200	HAZ	214–5356–5086	1255	39,700	HAZ
	1285	40,700	HAZ		1285	40,500	HAZ
	1290	40,400	HAZ		1280	40,800	HAZ
	1285	42,000	HAZ		1320	41,900	HAZ
	1275	40,300	HAZ		1270	41,200	HAZ
	1245	41,500	HAZ		1265	40,700	HAZ
	1250	40,700	HAZ		1275	40,200	HAZ
	1305	41,000	HAZ		1240	40,800	HAZ
Al – 7% Mg–5356–5086	1225	40,300	HAZ	214–4043–5086	1330	41,200	HAZ
	1230	38,000	HAZ		1315	40,800	HAZ
	1300	42,500	HAZ		1315	40,700	HAZ
	1270	41,100	HAZ		1295	19,400	W
	1260	39,700	HAZ		1350	41,900	HAZ
	1250	40,500	HAZ		1305	40,400	HAZ
	1275	40,500	HAZ		1300	41,400	HAZ
	1260	40,400	HAZ		1340	41,600	HAZ
356-T7–5052–5086	1270	39,000	HAZ	214–5154–5086	1245	39,800	HAZ
	1265	39,400	HAZ		1270	39,300	HAZ
	1300	39,200	HAZ		1285	41,300	HAZ
	915	11,100	W		1290	40,600	HAZ
	1265	39,900	HAZ		1240	34,200	HAZ
	1240	38,400	W-FZ		1260	40,400	HAZ
	1285	39,200	W-FZ		1270	39,300	HAZ
	1155	13,900	W		1260	38,600	HAZ
356-T7–4043–5086	1255	20,600	W-FZ				
	1290	39,900	HAZ				
	1210	23,400	W-FZ				
	1240	37,200	HAZ				
	1280	15,400	W				
	1090	11,600	W				
	1295	40,600	HAZ				
	677	8,100	W				

[a] HAZ = Heat-affected zone of the 5086 sheet; W = weld; W-FZ = partially in the weld and partially in the fusion zone of the 5086 sheet.

vealed no clear indication of any difference in weld quality which could be related to the various welding procedures. Very little scattered porosity was observed. Tungsten inclusions were present in a few welds. There were, however, indications of linear porosity apparently associated with incomplete penetration. Subsequent visual examination of the welds frequently revealed linear irregularities in the weld reinforcement at the base of the joint, which were similar to those noted in the radiographs. Therefore, neither the true nature nor the severity of the defects could be ascertained with any degree of certainty from the radiographs.

Tensile-test results: The ultimate tensile results of all the specimens are presented in Tables 6 through 9.

An examination of the fractured tensile-test specimens disclosed that the majority of failures occurred in the heat-affected zone of the 5086 sheet. Thus, the limiting factor of the chosen joint design was the strength of the annealed 5086 sheet. The remaining specimens failed in the weld region with failures in several specimens occurring partially in the weld and partially in the fusion zone. As might be expected in view of the 3 to 1 thickness ratio between the casting and sheet, no failure occurred in the cast member.

Table 10 contains the number of specimens in each combination that failed in the weld and in the weld-fusion zone. It will be noted that all of the weld-fusion-zone failures (totaling 11) occurred in those material combinations (DB, DC and EC) wherein silicon was a major alloying element either in the casting or in the filler wire. Another interesting fact is that 9 of the 11 failures occurred when a backing strip was employed. These figures appear significant, with the implication that the structurally weak zone which developed was probably due to the formation of magnesium silicide.

With reference to weld failures, the figures indicate that both magnesium silicide and welding with no backing strip were probably contributing factors. A comparison of the welding methods disclosed that a greater number of failures occurred when no backing strip was used. On the other hand, when a backing strip was used, all but two of the failures occurred in the 356 – 5086 (casting - to - sheet) combinations (DB and DC), with one of the exceptions being the combination 214–4043–5086 (EC).

The total number of weld failures that occurred in each of the two combinations with a backing strip (DB and DC) approximately equaled or surpassed the total number of weld failures that occurred with the same material combinations and no backing strip. When considering those methods wherein a backing strip was not used, it appeared that magnesium silicide had little or no influence in causing the welds to fail in combinations DB, DC and EC, since a number of failures also occurred under comparable conditions in combinations such as AA and ED, in which silicon, essentially, was not present.

It is recognized that the number

Table 7—Ultimate Tensile Results of Transverse-weld Specimens Removed from $^{3}/_{16}$-in. Thick Castings Joined to $^{1}/_{16}$-in. Thick 5086 Wrought Alloy. Each Joint Was Welded on One Side with the Use of an Inert-gas Purge and a Backing Strip

Weldment	Ultimate tensile load, lb	Ultimate tensile strength, psi	Fracture location[a]
Almag 35–5356–5086	1330	42,200	HAZ
	1320	42,400	HAZ
	1330	41,800	HAZ
	1320	41,600	HAZ
	1285	39,400	HAZ
	1280	40,400	HAZ
	866	10,000	W
	1330	42,000	HAZ
Al – 7% Mg–5356–5086	1230	40,100	HAZ
	1260	40,400	HAZ
	1245	38,800	HAZ
	1240	41,300	HAZ
	1260	40,400	HAZ
	1255	40,500	HAZ
	1250	39,100	HAZ
	1235	40,400	HAZ
356-T7–5052–5086	1285	41,200	HAZ
	1280	24,700	W
	557	6,800	W
	1305	41,600	HAZ
	1135	11,500	W
	930	10,600	W
	870	11,300	W
	1385	40,000	HAZ
356-T7–4043–5086	1090	12,400	W
	1275	24,300	W-FZ
	1295	36,600	W-FZ
	1060	14,300	W
	1225	40,000	HAZ
	1230	38,200	HAZ
	1280	27,800	W-FZ
	1235	15,500	W
214–5356–5086	1300	42,200	HAZ
	1260	40,000	HAZ
	1290	42,200	HAZ
	1305	41,300	HAZ
	1310	41,200	HAZ
	1305	41,000	HAZ
	1310	41,200	HAZ
	1315	41,900	HAZ
214–4043–5086	1315	38,900	HAZ
	1310	25,000	W-FZ
	1270	24,700	W-FZ
	1330	39,000	HAZ
	1300	41,300	HAZ
	1305	40,500	HAZ
	1295	41,800	HAZ
	1345	40,800	HAZ
214–5154–5086	1290	40,800	HAZ
	1300	39,000	HAZ
	1285	39,100	HAZ
	1290	41,000	HAZ
	1305	41,200	HAZ
	1330	41,200	HAZ
	1285	41,100	HAZ
	1255	40,600	HAZ

[a] HAZ = Heat-affected zone of the 5086 sheet; W = weld; W-FZ = partially in the weld and partially in the fusion zone of the 5086 sheet.

of samples considered in this evaluation is not great. Nevertheless, the data strongly suggest that, for all material combinations tested, welding the thin members without a backing strip promoted weld failures. In those combinations wherein silicon was an alloying element of the filler rod and/or one of the base members, it was quite possible that magnesium silicide had an influential part in causing the weld and weld-fusion-zone failures, particularly when a backing strip was used.

These failures in the immediate weld region may possibly be explained in that, when welding thin members without a backing strip, the operation is critical. The operator must continually maintain a deposition rate which, upon slight variation, could cause "burn-through" and loss of metal or poor fusion and incomplete penetration. The lack of fusion and penetration was obvious when examining the fractured specimens of these series. By employing the backing strip, however, the operator can weld with greater assurance of adequate fusion and penetration without "losing" the weld puddle. Under these conditions, the deposit is molten for a greater period of time. Consequently, should magnesium and silicon be present, a greater opportunity exists for the formation of the brittle intermetallic compound. Thus, the zone could be sufficiently weakened to cause failure, even though the weld may be thicker than the base member.

3/8-in. Thick Casting Welded to 3/8-in. Thick 5086 Wrought Plate

Radiographic Examination: The tensile-test specimens were X-rayed, as previously indicated. It was found that the radiographs disclosed some porosity and tungsten inclusions. The greatest amount of porosity was indicated in the weld zone of the specimens machined from the 42B-T6–5052 filler–5086 weldment. It was believed that these defects would not significantly influence the tensile properties of the joint. The results of the tensile test confirmed this opinion, since all the specimens failed in the cast member of the weldment and not through the weld.

Tensile-test Results: Three specimens of each cast alloy–filler metal–5086 alloy combination were tensile tested. The transverse tensile properties of each combination and the estimated standard deviation ($\hat{\sigma}$) are shown in Table 11. The above transverse tensile properties are illustrated by the graph shown in Fig. 5.

All of the specimens broke in the cast member, except for one specimen of the Almag 35–5356–5086 combination. This specimen broke in the fusion zone of the cast alloy. The strength of this specimen, however, was not appreciably lower than the tensile strength of the two similar specimens. Thus, the strength of the welded casting, in the material combinations tested, was essentially the factor limiting the ultimate strength of joints having a uniform thickness.

It will be noted that the strength

Table 8—Ultimate Tensile Results of Transverse-weld Specimens Removed from 3/16-in. Thick Castings Joined to 1/16-in. Thick 5086 Wrought Alloy. Each Joint Was Welded on One Side Without the Use of a Backing Strip

Weldment	Ultimate tensile load, lb	Ultimate tensile strength, psi	Fracture location[a]	Weldment	Ultimate tensile load, lb	Ultimate tensile strength, psi	Fracture location[a]
Almag 35–5356–5086	573	7,000	W	214–5356–5086	1250	17,300	W
	955	10,400	W		1315	40,700	HAZ
	1345	40,800	HAZ		1275	41,000	HAZ
	679	7,500	W		1140	14,500	W
	1305	41,200	HAZ		1160	14,000	W
	1285	40,400	HAZ		1305	41,600	HAZ
	1275	41,100	HAZ		1325	40,900	HAZ
	1350	42,200	HAZ		1280	40,000	HAZ
Al – 7% Mg–5356–5086	784	10,400	W	214–4043–5086	490	7,000	W
	1245	40,000	HAZ		1310	40,800	HAZ
	1270	40,400	HAZ		1305	39,000	W-FZ
	1215	40,100	HAZ		1320	40,600	HAZ
	1245	39,600	HAZ		995	14,900	W
	1290	41,600	HAZ		1335	40,700	HAZ
	1270	40,400	HAZ		1340	41,700	HAZ
	1255	39,700	HAZ		1345	40,900	HAZ
356-T7–5052–5086	207	2,200	W	214–5154–5086	970	12,100	W
	1195	40,100	HAZ		1275	39,400	HAZ
	1255	40,600	HAZ		1255	39,700	HAZ
	352	4,700	W		1200	15,300	W
	785	9,800	W		1260	40,900	HAZ
	1320	40,500	HAZ		1235	15,600	W
	1310	33,400	W-FZ		1255	39,600	HAZ
	1300	40,500	HAZ		1185	15,100	W
356-T7–4043–5086	1305	40,500	HAZ				
	1330	41,700	HAZ				
	1330	41,400	HAZ				
	960	12,000	W				
	1270	40,600	HAZ				
	1290	41,300	HAZ				
	1295	40,700	HAZ				
	650	8,500	W				

[a] HAZ = Heat-affected zone of the 5086 sheet; W = weld; W-FZ = partially in the weld and partially in the fusion zone of the 5086 sheet.

Table 9—Ultimate Tensile Results of Transverse-weld Specimens Removed from $^{3}/_{16}$-inch Thick Castings Joined to $^{1}/_{16}$-inch Thick 5086 Wrought Alloy. Each Joint Was Welded on Both Sides without the Use of a Backing Strip

Weldment	Ultimate tensile load, lb	Ultimate tensile strength, psi	Fracture location[a]	Weldment	Ultimate tensile load, lb	Ultimate tensile strength, psi	Fracture location[a]
Almag 35–5356–5086	1225	12,100	W	214–5356–5086	1325	42,200	HAZ
	1270	41,500	HAZ		1325	41,700	HAZ
	1355	41,700	HAZ		1330	42,000	HAZ
	990	9,600	W		1330	41,800	HAZ
	1310	41,900	HAZ		1320	40,900	HAZ
	1325	40,600	HAZ		1335	41,500	
	1355	42,200	HAZ		1335	42,400	HAZ
	1140	11,100	W		1300	40,500	HAZ
Al – 7% Mg–5356–5086	1310	41,300	HAZ	214–4043–5086	885	10,700	W
	1305	41,200	HAZ		1330	41,600	HAZ
	1330	41,000	HAZ		1325	41,700	HAZ
	1335	41,700	HAZ		1320	41,500	HAZ
	1320	40,700	HAZ		1075	10,600	W
	1325	40,900	HAZ		1330	42,600	HAZ
	1315	40,600	HAZ		1250	36,800	HAZ
	1340	41,000	HAZ		1080	11,500	W
356-T7–5052–5086	1250	41,400	HAZ	214–5154–5086	1295	41,000	HAZ
	1235	10,700	W		1320	41,100	HAZ
	1250	41,800	HAZ		1300	40,600	HAZ
	1130	10,500	W		1215	14,800	W
	1220	11,100	W		1300	40,900	HAZ
	1185	10,000	W		1260	41,200	HAZ
	1275	40,700	HAZ		1275	40,300	HAZ
	1255	11,300	W		1320	41,600	HAZ
356-T7–4043–5086	1310	41,500	HAZ				
	1350	41,800	HAZ				
	1310	41,600	HAZ				
	1325	41,100	HAZ				
	1310	40,700	HAZ				
	1300	40,400	HAZ				
	1320	41,000	HAZ				
	1265	15,000	W				

[a] HAZ = Heat-affected zone of the 5086 sheet; W = weld.

Table 10—Number of Specimen Failures Through the Weld and the Weld-fusion Zones (Each Weldment Consisted of $^{3}/_{16}$-in. Thick Casting Welded to $^{1}/_{16}$-in. Thick 5086 Wrought Alloy)

	Combinations															
	AA		CA		DB		DC		EA		EC		ED		Total	
Weld method	Weld	Weld-fusion zone	Weld	Weld-fusion zone	Weld	Weld-fusion zone	Weld	Weld-fusion zone	Weld	Weld-fusion zone	Weld	Weld-fusion zone	Weld	Weld-fusion zone	Weld	Weld-fusion zone
Welded one side, backing strip	0	0	0	0	2	2	3	2	0	0	1	0	0	0	6	4
Welded one side, inert-gas purge and backing strip	1	0	0	0	5	0	3	3	0	0	0	2	0	0	9	5
Welded one side, no backing strip	3	0	1	0	3	1	2	0	3	0	2	1	4	0	18	2
Welded both sides, no backing strip	3	0	0	0	5	0	1	0	0	0	3	0	1	0	13	0
Total	7	0	1	0	15	3	9	5	3	0	6	3	5	0	46	11

Notes: (a)

Code	Cast aluminum alloy	Filler rod
AA	Almag 35	5356
CA	Al – 7% Mg	5356
DB	356-T7	5052
DC	356-T7	4043
EA	214	5356
EC	214	4043
ED	214	5154

(b) Tensile tests were conducted on eight specimens from each material combination welded with four welding methods. One hundred sixty-seven specimens failed in the heat-affected zone of the 5086 sheet.

of the Almag 35–5356–5086 combination is greater than the strength of any other combination tested. This might be expected since the tensile strength of Almag 35 normally exceeds the strength of the other cast alloys, excluding the heat-treated alloys. The tensile properties of the cast alloys are listed in Table 12.

For the purpose of this investigation, the properties of the as-welded combinations were considered. It was expected, therefore, that the strength of the heat-treated alloys (356-T7 and 42B-T6) adjacent to the weld would be affected, since these areas would be overaged as a result of welding. To show the extent of these overaged areas, Rockwell "F" hardness readings were taken on a typical specimen of each combination, approximately $^1/_8$ of an inch apart, for a distance of 1 in. on either side of the fracture. For those specimens in which the casting was a heat-treatable material, the hardness values in the areas adjacent to the fracture were noticeably less than the hardness values determined in any other portion of the specimens, with the exception of the weld itself. The typical fractured specimens and their Rockwell "F" hardness readings are shown in Figs. 6 and 7.

Summation of Results

It would seem appropriate, at this point to review briefly the results of this study. The results disclosed that the limiting factor of most of the joints which consisted of a $^3/_{16}$-in. thick casting welded to a $^1/_{16}$-in. thick 5086 wrought alloy was found to be the strength of the heat-affected zone in the 5086 sheet. The joints of the material combinations in which silicon was a major alloying element, either in the casting or in the filler wire, had, in some cases, a structurally weak zone due, probably, to the formation of magnesium silicide. Poor tensile properties due to lack of fusion resulted in a number of instances when the joint was welded without the use of a backing strip. In addition, gross porosity in the weld resulted from the joining of the Al–7% Mg–3% Zn alloy to the 5086 wrought alloy.

The results of testing specimens machined from welded material combinations of equal thickness disclosed that the strength of the casting was the limiting factor of the joint strength. The Almag

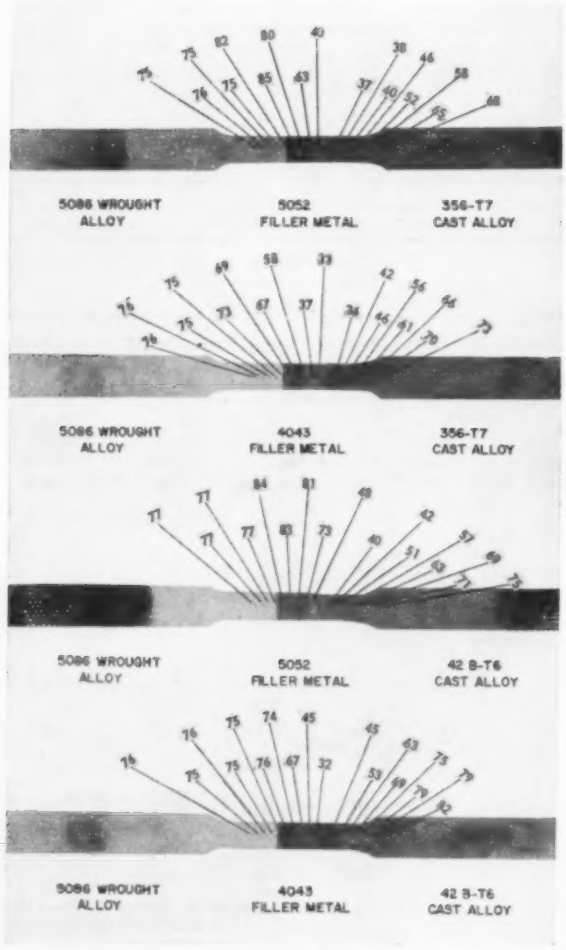

Fig. 6—Rockwell "F" hardness values obtained on typical fractured transverse-weld specimens removed from $^3/_8$-in. thick heat-treated cast alloys welded to $^3/_8$-in. thick 5086 wrought alloy; each weldment was machined to $^1/_4$-in. thickness before the specimens were removed

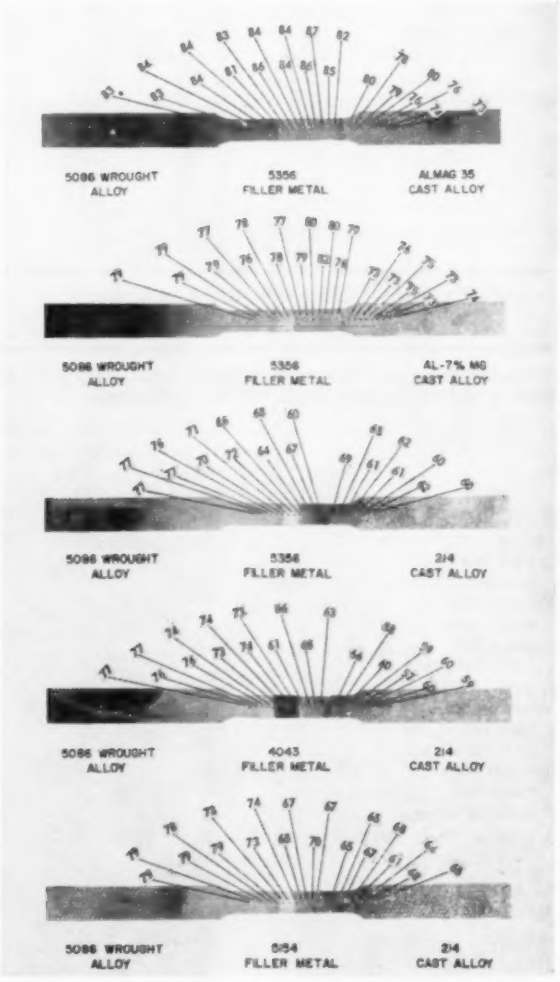

Fig. 7—Rockwell "F" hardness values obtained on typical fractured transverse-weld specimens removed from $^3/_8$-in. thick nonheat-treated cast alloys welded to $^3/_8$-in. thick 5086 wrought alloy; each weldment was machined to $^1/_4$-in. thickness before the specimens were removed

Table 11—Transverse Tensile Data on Welds of $^3/_8$-in. Thick Castings Joined to $^3/_8$-in. Thick 5086 Wrought Alloy. (Each Weldment Was Machined to $^1/_4$ in. Thickness)

Weldment	Ultimate tensile strength, psi	$\hat{\sigma}$[a]	Yield strength (0.2% offset) psi	$\hat{\sigma}$[a]	Elongation in 2-in. gage length, %	$\hat{\sigma}$[a]
Almag 35–5356–5086	36,100		21,400		5.6[b]	
	32,800		21,400		4.5[b]	
	33,800		22,000		5.7[c]	
Avg.	34,200	1700	21,600	300	5.3	0.7
Al – 7% Mg–5356–5086	26,600		19,100		2.4[b]	
	25,800		19,400		2.6[b]	
	24,600		19,100		2.3[b]	
Avg.	25,700	1000	19,200	200	2.4	0.1
356-T7–5052–5086	21,600		14,300		4.2	
	20,900		14,600		4.3	
	22,500		14,700		5.0	
Avg.	21,700	800	14,500	200	4.5	0.4
356-T7–4043–5086	22,100		15,400		4.4	
	21,700		16,000		4.2	
	21,900		14,200		4.1	
Avg.	21,900	200	15,200	900	4.2	0.1
214–5356–5086	24,200		14,200		4.3	
	24,300		14,600		4.8	
	25,300		14,400		4.0[b]	
Avg.	24,600	600	14,400	200	4.4	0.4
214–4043–5086	23,400		13,500		4.0	
	24,200		14,500		4.9	
	22,500		15,100		2.4[b]	
Avg.	23,400	800	14,400	800	3.8	1.3
214–5154–5086	26,600		14,400		6.0	
	24,500		14,300		4.8	
	26,200		16,100		4.5[b]	
Avg.	25,800	1100	14,900	1000	5.1	0.8
42B-T6–5052–5086	23,300		15,600		4.8	
	23,100		15,300		4.0	
	22,600		15,000		4.3	
Avg.	23,000	400	15,300	300	4.4	0.4
42B-T6–4043–5086	22,000		15,100		3.4	
	22,600		16,300		2.8	
	22,500		16,400		3.0	
Avg.	22,400	300	15,900	700	3.1	0.3

[a] Estimated standard deviation.

[b] Broke outside of gage marks.

[c] Broke in fusion zone; all the other specimens broke in the cast member.

Table 12—Tensile Properties of Cast Aluminum Alloys

Cast aluminum alloy	Ultimate tensile strength, psi	Yield strength, (0.2% offset) psi	Elongation in 2-in. gage length, %
Almag 35	37,400	18,600	9.3
Al – 7% Mg	32,000	16,600	10.7
356-T7	41,500	35,300	3.8
214	25,000	12,500	8.0
42B-T6	42,000	32,000	3.0

35–5356–5086 combination was found to exhibit the highest joint strength of all the combinations.

Conclusions

The following conclusions seem warranted from this investigation.

1. The 214, Almag 35 and Al–7% Mg cast aluminum alloys can be satisfactorily welded to 5086 wrought aluminum-alloy sheet by using the gas tungsten-arc welding process and 5356 filler rod. Filler rod 5154 also can be used in welding 214 and, possibly, Almag 35 and Al–7% Mg castings to 5086 sheet under similar conditions.

2. When the casting was overmatched by the 5086 member, thereby forcing failure to occur in the casting, and the comparison was made between cast members of equal thickness, the material combination having the highest ultimate joint strength included Almag 35 followed by Al–7% Mg and 214, in that order but with very little difference between the latter two.

3. The welding of those casting–filler metal–5086 alloy combinations (such as 356–5052–5086, 42B–4043–5086 and 214-4043–5086), wherein both silicon and magnesium are major alloying elements, is less likely to result in joints of reasonable strength and ductility due to the possible formation of magnesium silicide.

4. The welding of Al–7% Mg–3% Zn alloy casting to 5086 sheet is least likely, of all the combinations investigated, to result in joints of reasonable strength and ductility due to the development of gross porosity in the weld.

5. Lack of fusion and failures in the weld region with correspondingly poor tensile properties are more apt to occur if no backing strip is employed when welding thin members.

Acknowledgments

The authors wish to acknowledge the assistance of the staff of the Pitman-Dunn Laboratories Groups of Frankford Arsenal. They are indebted particularly to H. Markus, Director of Metallurgical Research Laboratory Branch and F. W. Hussey, Chief, Metal Joining Section for their guidance and direction throughout the program. Special thanks are also due to H. Sulinski who provided the cast materials and to K. Ritthaler who supervised the welding and machining operations.

Low-Temperature Properties of Welded Magnesium Alloys

Paper provides additional data on the newer magnesium-alloy compositions and on the properties of welds in these alloys at low temperatures

BY R. W. FENN, JR. AND L. F. LOCKWOOD

ABSTRACT. This paper presents the results of a room- and low-temperature weld-test program conducted on AZ31B, HK31A, HM21A, ZE10A and ZE41XA magnesium sheet and plate.

In general, the strengths of both base metal and welds gradually increase with decreasing test temperature. The magnitude of the increase is greater for the base metal than for the welds. Ductilities of the base metal and welds gradually decrease with reduction in test temperature. A similar increase in strength and decrease in ductility is noted in the all-weld metal properties of EZ33A and AZ61A weld deposits at low temperature. Maximum base metal and weld strengths at low temperatures are obtained on AZ31B base metal welded with AZ61A filler rod.

Introduction

The properties of metals at low temperatures have become increasingly important in recent years due to the low temperatures being encountered in high-flying aircraft and in the handling of liquefied gases. The excellent strength-to-weight ratio of magnesium alloys offers the designer significant weight savings combined with excellent weldability, formability, machineability and thermal characteristics. A limited amount of low-temperature property data on currently commercial magnesium alloys has appeared in the literature.[1-5] It is the purpose of this paper to provide additional data on the newer alloy compositions and on the properties of welds in these alloys at low temperatures. Since the welding characteristics of the current magnesium alloys have been adequately defined in recent literature,[6,7] no detailed discussion of weldability will be presented.

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Composition and Physical Properties

The nominal composition and physical properties of the magnesium base alloys used in this investigation are summarized in Table 1. The AZ31B, ZE10A and ZE41XA compositions are normally used for applications at temperatures up to approximately 300 or 400° F while the HK31A and HM21A compositions are designed for elevated-temperature service and are used at temperatures up to approximately 800 or 900° F.

Procedure

All welds were made with the inert-gas-shielded tungsten-arc process using an a-c high-frequency stabilized source of power, helium shielding gas and the recommended filler rod for the base metal being welded. All materials were wire-brush cleaned on both surfaces and edges prior to welding. A schematic view of the welding procedure used to make the butt welds and all-weld-metal bars is given in Fig. 1. Butt welds in the 0.125-in. thick sheet

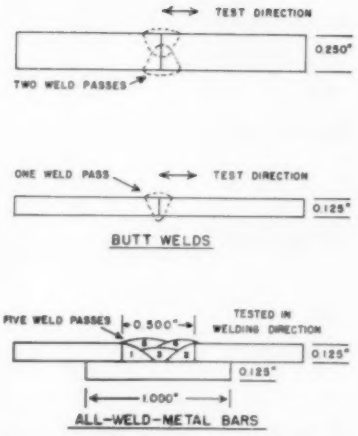


Fig. 1—Schematic view of welding procedure used to make room- and low-temperature test bars

Table 1—Composition and Physical Properties of Magnesium-base Alloys

Alloy	Al, %	Mn, %	RE, %	Th, %	Zn, %	Zr, %	Specific gravity	Thermal conductivity, cgs units, 20° C	Solidification range, ° F
Sheet and plate alloys									
AZ31B	3.0	0.20 min	...	...	1.0	...	1.77	0.18	1050–1160
HK31A	...	...	...	3.3	...	0.7	1.80	0.27	1092–1195
HM21A	...	0.6	...	2.0	...	...	1.78	0.33	1121–1202
ZE10A	...	...	0.17	...	1.2	...	1.76	0.33	1100–1195
ZE41XA	...	...	0.6	...	4.3	0.45	...	...	...
Filler rods									
AZ61A	6.5	...	...	...	1.0	...	1.80	0.14	990–1145
EZ33A	...	...	3.0	...	2.7	0.7	1.83	0.24	1010–1189

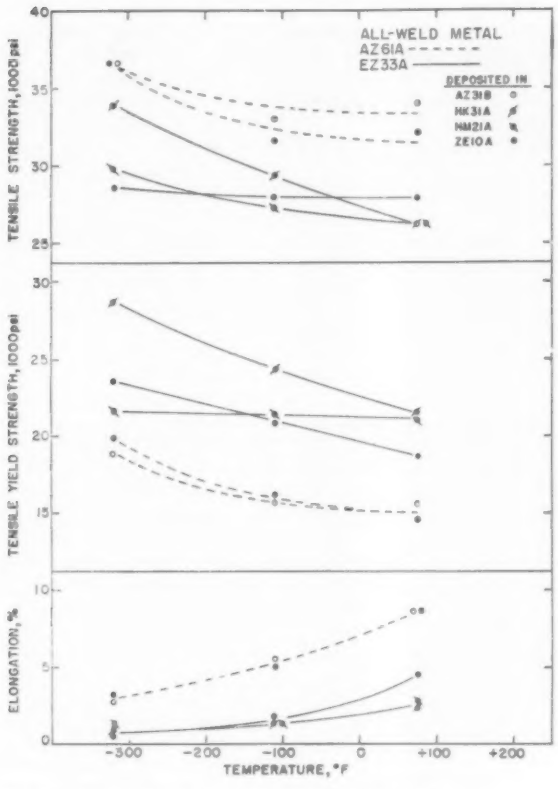


Fig. 2—All-weld-metal properties of EZ33A and AZ61A weld deposits at room and low temperature

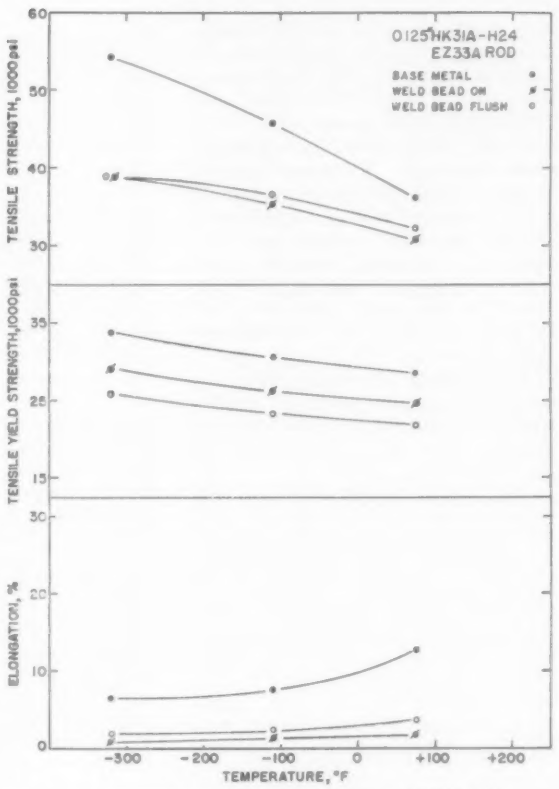


Fig. 4—Low-temperature properties of 0.125-in. HK31A-H24 sheet welded with EZ33A filler rod

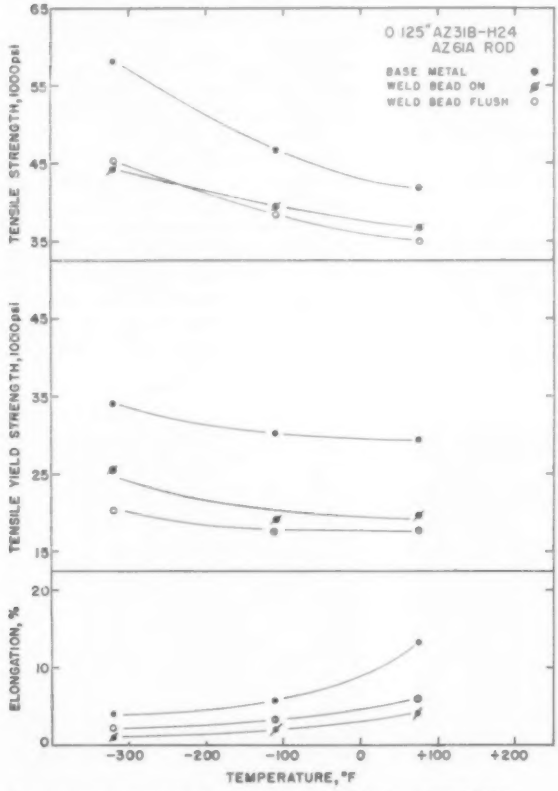


Fig. 3—Low-temperature properties of 0.125-in. AZ31B-H24 sheet welded with AZ61A filler rod

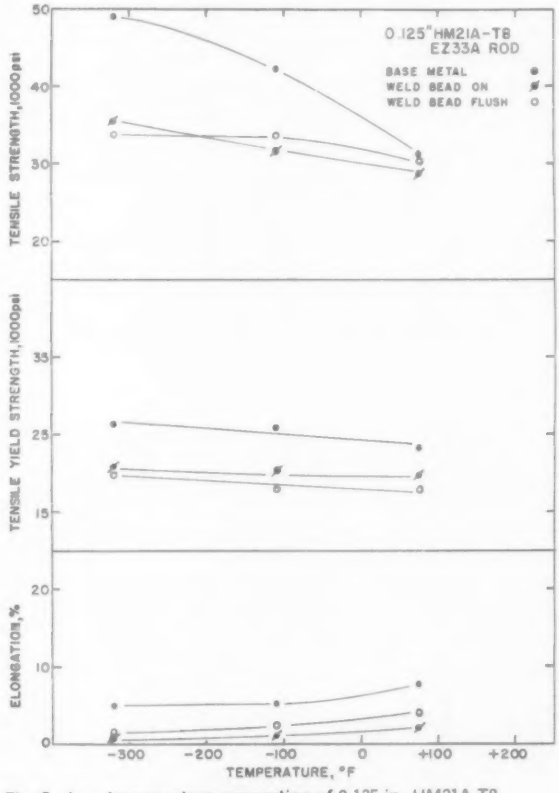


Fig. 5—Low-temperature properties of 0.125-in. HM21A-T8 sheet welded with EZ33A filler rod

were made using a free drop-down technique with argon-gas backing to aid in producing uniform weld penetration. In the 0.250-in. thick material two weld passes, one from each side of the plate, were used to make the weld. Tensile properties of these weldments were determined on test bars cut with the weld in the middle of the reduced section, transverse to the test direction. Five weld passes were used to deposit the all-weld-metal test bars between the two pieces of 0.125-in. thick sheet spaced $^1/_2$ in. apart. All-weld-metal properties were determined on specimens cut in the weld direction so that the reduced section consisted entirely of weld metal.

A 50,000-lb capacity screw-driven universal testing machine was used for tensile testing. Microformer extensometers and a microformer load-strain recorder were used to measure strain. Specimens were strained at a rate of 0.005 in./in./min. from zero to one percent strain and 0.1 in./in./min. from one percent strain to failure. Test specimens were made in accordance with ASTM test method E8-57T, except that the reduced section for the low-temperature test specimens was smaller than specified (0.400 in. in lieu of 0.500 in.) to insure failure in the reduced section. Elongation measurements were made over two inches.

The test temperature of −109° F was obtained by immersing the test specimen, shackles and extensometer extension arms in a bath of dry ice and alcohol during testing. The −321° F test temperature was obtained by using a bath of liquid nitrogen in a similar manner. Before beginning a test, the specimen was held in the low-temperature bath until a thermocouple attached to the reduced section of the specimen indicated that the specimen had attained equilibrium at the temperature of the bath.

Results and Discussion

Properties of Weld-metal Deposits

The tensile properties of the all-weld-metal deposits of AZ61A and EZ33A rods tested at 75, −109 and −321° F are plotted graphically in Fig. 2. The tensile strength of the weld deposit gradually increases and the percent elongation gradually decreases with decreasing temperature. The highest strengths at room and low temperature are obtained with the AZ61A filler rod. On the basis of all-weld-metal strength, AZ61A filler rod would be expected to offer the best low-temperature weldment strength. Variations in weld-deposit strength with the various base metals are due to alloying between the filler rod and base metal during welding.

Low-temperature Weld Properties

The short-time longitudinal tensile properties of welded AZ31B, HK31A, HM21A, ZE10A and ZE41XA sheet alloys at room and low temperature are plotted graphically in Figs. 3 to 7, respectively.

In general, the strength of the magnesium-alloy welds gradually increases while percent elongation decreases with reduction in temperature. The magnitude of the strength increase is greater for the base metal than for the welds resulting in a gradual decrease in the weld-strength efficiency as test temperature is reduced (see Figs. 3 to 7).

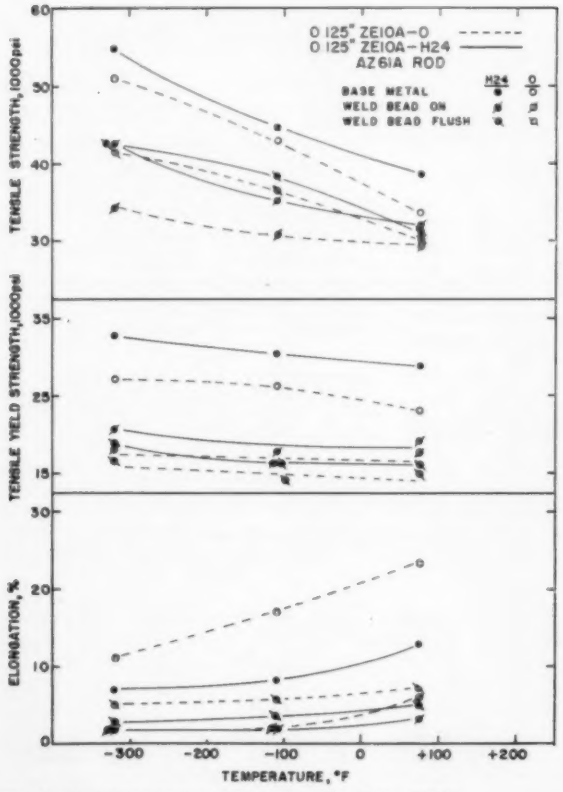


Fig. 6—Low-temperature properties of 0.125-in. ZE10A sheet welded with AZ61A filler rod

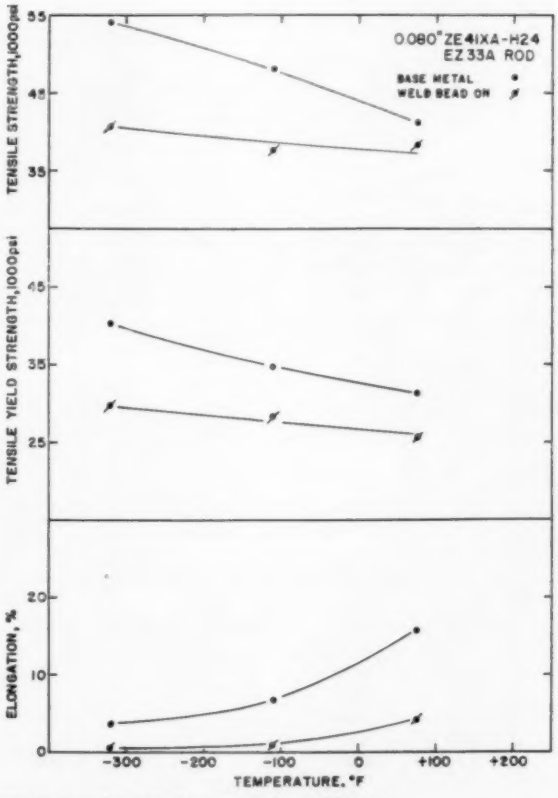
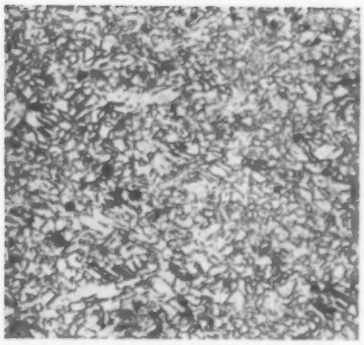
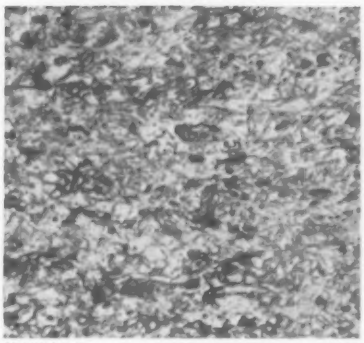


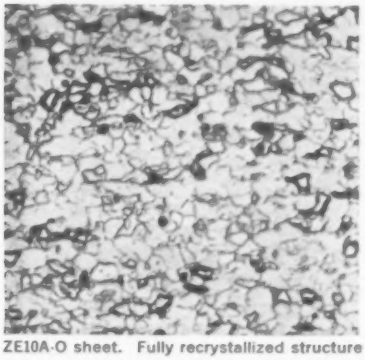
Fig. 7—Low-temperature properties of 0.080-in. ZE41XA-H24 sheet welded with EZ33A filler rod



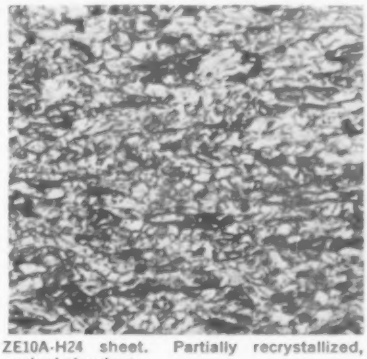
AZ31B-H24 sheet. Partially recrystallized, worked structure



ZE41XA-H24 sheet. Partially recrystallized, worked structure



ZE10A-O sheet. Fully recrystallized structure



ZE10A-H24 sheet. Partially recrystallized, worked structure

Fig. 8—Microstructure of wrought Mg-Al-Zn and Mg-Zn-RE alloys. Acetic-picral etch. × 250

Higher tensile strength and percent elongation values are generally obtained with the weld beads ground flush than with the weld bead intact as a result of the elimination of notch effects. With the exception of ZE10A welds, fractures occurred in the heat-affected zone with the weld bead intact and in the weld metal with the bead machined flush. In the ZE10A flush-machined welds, the fractures occurred in the heat-affected zone at room temperature and in the weld metal at low temperature. The maximum low-temperature strength of both base metal and welds is obtained with AZ31B-H24 alloy welded with AZ61A filler rod. No significant variation in the net change in mechanical properties resulting from decreasing temperature was found between different thicknesses of material or different tempers (e.g., −H24 vs. −0).

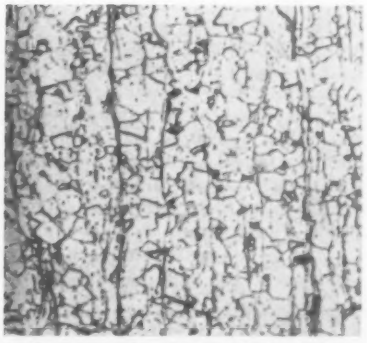
Low-temperature Base-metal Properties

The tensile properties of the AZ31B, HK31A, HM21A, ZE10A and ZE41XA base metal show increases of approximately 13,000–18,000 psi in tensile strength and 3000–9000 psi in tensile yield strength as the test temperature is reduced from 75 to −321° F. The greatest net change in properties is obtained with the HK31A alloy but the highest level of low-temperature properties is realized with the AZ31B composition because of its higher room-temperature strength. Base-metal percent elongation decreases with decreasing test temperature.

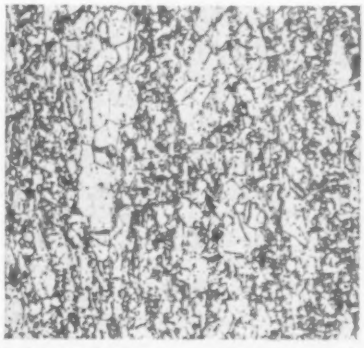
Metallography

The typical microstructures of the various wrought Mg-Al-Zn and Mg-Zn-RE alloys are shown in Fig. 8 while the Mg-Th-Mn and Mg-Th-Zr alloys are shown in Fig. 9. The AZ31B-H24, ZE41XA-H24, ZE10A-H24 and HK31A-H24 compositions show a partially recrystallized, work-hardened grain structure while the ZE10A-0 and HK31A-0 compositions have a recrystallized structure. Although the HM21A-T8 composition shows a cold-worked-and-aged structure, the precipitate is too fine to be seen at × 250 magnification.

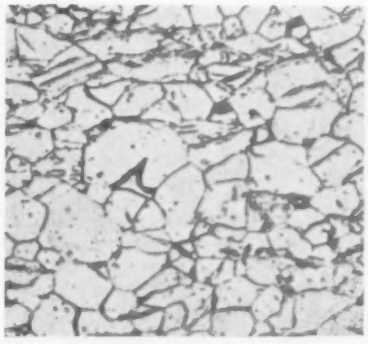
The effect of the weld thermal cycle on the appearance of the weld-metal junction is shown in Figs. 10 and 11. A narrow zone of complete recrystallization with some grain growth has occurred as a result of the welding heat. This annealing and grain growth account for the somewhat lower room-temperature strength of the alloys after welding. It is the exceptionally large grain size in the junction of the weld in ZE10A-H24 sheet that causes some tensile failures to occur in the weld heat-affected zone rather than in the weld, even though the weld bead has been machined flush. From Figs. 10 and 11, it is evident that the AZ61A and EZ33A weld deposits consist of relatively fine, equiaxed grains. It is the fine grain size that



HK31A-O plate. Fully recrystallized structure



HK31A-H24 sheet. Partially recrystallized, worked structure

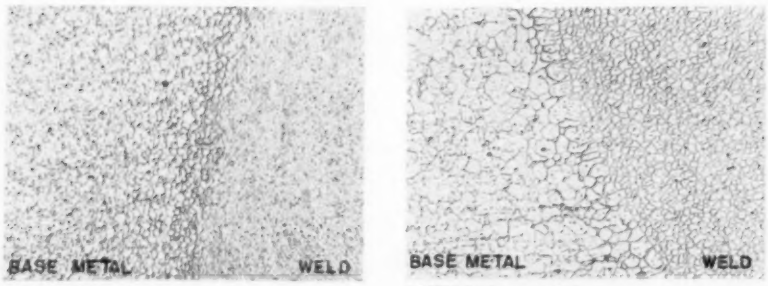


HM21A-T8 sheet. Cold worked and aged structure

Fig. 9—Microstructure of wrought Mg-Th-Mn and Mg-Th-Zr alloys. Phospho-picral etch. × 250

AZ31B-H24 welded with AZ61A rod | ZE10A-H24 welded with AZ61A rod | ZE41XA-H24 welded with EZ33A rod

Fig. 10—Weld junctions of wrought Mg-Al-Zn and Mg-Zn-RE alloys welded with AZ61A and EZ33A filler rods. Acetic-picral etch. × 100. (Reduced by 40% upon reproduction)



HK31A-H24 base metal | HM21A-T8 base metal

Fig. 11—Weld junctions of wrought Mg-Th-Mn and Mg-Th-Zr alloys welded with EZ33A filler rod. Phospho-picral etch. × 100. (Reduced by 40% upon reproduction)

accounts for the good room-temperature weld strength with these filler-rod alloys.

Summary of Results

Significant increases in strength and slight decreases in percent elongation are noted with decreasing test temperature for both the welded and unwelded alloys. All-weld-metal data indicate that the highest strength and percent elongation values are obtained with AZ61A filler rod. Metal temper or sheet thickness do not affect the net change in properties resulting from a decrease in test temperature. Maximum low-temperature strength of base metal and welds is obtained with AZ31B-H24 alloy using an AZ61A filler rod.

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WRC Bulletin No. 60

"An Experimental Investigation of Stresses in the Neighborhood of Attachments to a Cylindrical Shell"

Welding Research Council Bulletin No. 60 to be published in June 1960 describes an extensive research program carried out at Cornell University to provide designers with needed information for computing stresses in cylindrical and spherical shells due to loadings which impose localized radial forces or longitudinal or circumferential moments. This research project was sponsored by the Design Division of the Pressure Vessel Research Committee through its Subcommittee on External Loadings of Pressure Vessels with financial assistance from the Bureau of Ships of the U. S. Navy. Checks against available published experimental data indicated reasonable agreement but since such data was extremely limited, these tests were carried out to provide additional data for checking of the theory.

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Circular-Patch Test for Evaluating Armor Crack Susceptibility

Object of investigation is to determine the suitability of the circular patch as a test of the susceptibility of base metal to cracking in welded joints of Ordnance armor-steel weldments

BY LAURENCE E. POTEAT AND RICHARD W. JONES

ABSTRACT. No fully acceptable test is available to determine the weldability of Ordnance armor. The literature indicates that the circular-patch test has many qualities which are desirable in a weldability test, but techniques for applying it as a weldability test have not been fully investigated and the test is not standardized. An investigation was conducted to determine the effect of different procedures on the effectiveness of the circular-patch test specimen in the evaluation of plate crack susceptibility and to determine conditions suitable for a standard test. A test procedure was selected and used on several different heats of armor steel. Evaluation of these heats by this procedure placed the heats in the correct order of crack susceptibility as determined from the known fabrication history of the heats.

Introduction

The present policy on purchasing armor plate for Ordnance purposes is by specifications of chemical analysis, hardness, ballistic properties and Charpy-impact value. This takes into consideration all of the pertinent properties of the steel with the exception of the weldability of the steel. No one group is in a better position to appreciate this than the fabricators who are working with armor steels. The fabricator receives heats to specifications and is able to detect the heats that are weld-crack sensitive only after the steel is used in production of vehicles.

Weldability has been defined by the AMERICAN WELDING SOCIETY[1] "as the capacity of a metal to be welded under the fabrication conditions imposed into a specific, suitably designed structure, and to perform satisfactorily in the intended service." As welding is the most used method of fabricating Ordnance Corps end items, weldability is a very important consideration in procurement of materials. Many different weldability tests have been devised and used,[2] but as yet no test has been adopted by the Ordnance Corps due to their inability to indicate conclusively which heats are weld-crack sensitive and which are not.

The ideal test or group of tests for weldability evaluation should have the following characteristics as pointed out by Stout and Doty:

(*a*) High sensitivity to the effects of welding.
(*b*) Good reproducibility.
(*c*) Simplicity of specimen preparation and testing procedure.
(*d*) Direct correlation with fabrication requirements and service requirements.

The circular-patch test has been used for several years by the Navy Department, Bureau of Ships, for qualification of electrodes.[3] Other investigators have used a circular-groove specimen[4] for restraint cracking of weld deposits. Circular-patch tests for underbead cracking have been developed and used by Hoyt[5] and Voldrich[6] for testing sheet steels for underbead cracking.

The circular-patch test lends itself readily as a weldability test by virtue of its simplicity in preparation, use of conventional welding procedure, its high restraint, and its ease of restraint control, which permit testing the fabricability of the metal; also, the product of the test is a flat plate which permits performance tests such as ballistic tests, etc. As both joinability (fabricability) and performance are necessary for a complete weldability test, the circular patch can be used to determine both.

This investigation was limited to an evaluation of different conditions and procedures for producing a circular-patch type test to determine the crack susceptibility or joinability properties of armor plate. The effectiveness of selected test conditions was evaluated by applying these conditions to several heats of armor which had known fabrication history to determine if the test is sensitive enough to separate the crack-susceptible plates from the crack-resistant plates.

The object of this investigation was to determine the suitability of the "circular patch" as a test of the susceptibility of base metal to cracking in welded joints of Ordnance armor-steel weldments.

Materials and Procedure

Plan of the Investigation

The circular-patch type test can be made under a variety of conditions. The total of all of these was an impractical array of conditions and tests. To expedite the program, it was decided to divide the investigation into two phases; the first phase to be limited to one heat of armor plate using selected test conditions. If possible, a heat would be used which had known fabrication history or which was being used in other investigations. Some conditions were arbitrarily set, based on procedures similar to those used in production fabrication, but keeping the desired characteristics of an acceptable weldability test in mind. The conditions which were to be held

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The opinions herein expressed are those of the authors and do not necessarily represent those of the Ordnance Corps.

Table 1—Armor Plate Materials

Heat	0724	0303	0823	0521	0191	0681	0140	0531
Hardness								
Bhn	352	363	352	375	363	363	363	363
R_c	35	37	35	36	37	38	39	37
Impact, ft-lb								
Room temperature	16	25	30	20	15@ −18°C	26	20	26
−40° F	14	11	17	14	...	16	16	14
Tensile								
Yield strength, psi	...	162,500	...	...	...	...	...	162,700
Tensile strength, psi	...	176,900	...	...	...	...	...	173,800
Elongation, %	...	12.5	...	...	...	...	...	13.9
Reduction Area, %	...	47	...	...	...	...	...	52
Chemistry								
C, %	0.26	0.27	0.27	0.27	0.26	0.30	0.29	0.28
Mn, %	1.57	1.87	1.68	1.67	1.71	1.66	1.71	1.65
Si, %	0.18	0.19	0.18	0.20	0.20	0.28	0.19	0.14
S, %	0.019	0.014	0.022	0.021	0.018	0.013	0.018	0.015
P, %	0.012	0.019	0.016	0.016	0.025	0.015	0.015	0.014
Mo, %	0.45	0.50	0.41	0.46	0.50	0.46	0.51	0.53
B, %	...	...	Yes	...	...	Yes	Yes	...
Rare earth	(Oxide addition)	...	...	...	...	(Metal addition)	...	...
Fabrication history								
Ref. 9	...	Good	...	Good	Bad	...	Bad	Bad
Ref. 7	Best	...	Avg	...	...	Avg	...	...

constant in the first phase were to be heat of armor, welding operator, backing, groove preparation, welding machine, current and voltage. The factors to be investigated were welding sequence, type of electrode, preheat and interpass temperature. The diameter of the patch was to be varied to place the test plate under different conditions of restraint.

During welding of the specimen, any surface cracks observed were to be repaired. This would follow the usual fabrication practice and also produce a specimen which would permit further testing for serviceability, if necessary.

The second phase of the investigation would use the procedure developed in the first phase which gave the most selective results—i.e., cracking in the highly restrained specimen and no cracking in the lesser restrained specimen—and apply it to several heats of armor which have known production histories. The validity of the test would be determined by the correlation of test results with the known histories of the base metal.

Armor Plate

The armor plate used in this investigation was a homogeneous-type manganese-molybdenum armor of approximately 180,000 psi tensile strength and hardness of 340–380 Bhn. This armor is used by the Army Ordnance Corps for fabrication of vehicles produced to Army Specification, MIL-A-12560. Table 1 shows heats used and some of their properties.

For the first phase of the investigation, heat JL 0681, supplied by one steel producer, was selected. This heat was a special rare-earth metal-treated heat which had been investigated by Smith,[7] and its crack susceptibility had appeared to be about typical of this type of armor. Results of ballistic tests at Aberdeen Proving Ground[8] indicated that its ballistic properties were about average. Also, it was available in sufficient quantities to make a complete study.

The materials used for the second phase of the investigation, heat JL 0521 and heat JL 0303, were reported by Detroit Arsenal[9] to have good fabrication history, and heats JL 0140, JL 0531 and JL 0191 were reported as difficult to weld in production. Heats JL 0823 and JL 0724 were used with Heat 0681 in the rare-earth investigation by Smith, and all three were reported to be of average weldability.

Welding Electrode

In this investigation most of the circular-patch tests were made using electrodes produced under MIL-E-986 to conform to low-hydrogen type

Fig. 1—Oxygen cutting the circular-patch test plate. Insert shows line-up of tip for accurate cut

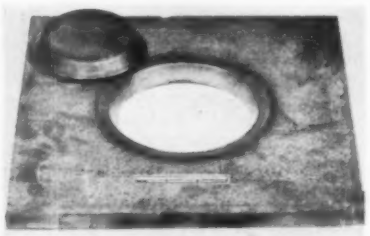

Fig. 2—Test plate for circular-patch test

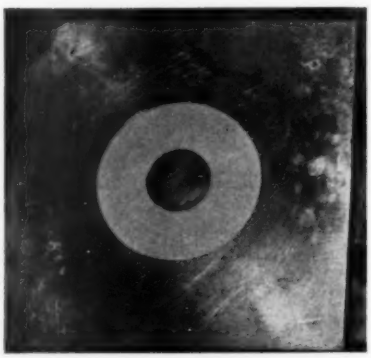

Fig. 3—Copper backing plate showing application of antispatter compound

Fig. 4—Circular-patch test-plate set up for welding

electrode in grades 180, 230 and 260. The entire series of electrodes was produced from one heat of core wire and each grade was produced from one batch of electrode covering. These were produced expressly for uniformity in research work. In addition, high-strength and stainless-steel electrodes were used as a comparison. For the root pass, $^5/_{32}$-in. diam electrodes were used and $^3/_{16}$-in. diam electrodes for the subsequent passes.

Cutting Equipment

One of the first obstacles to overcome was the problem of preparing the test plate. It was necessary to oxygen-cut the plate accurately into a test specimen which could be reproduced easily and, as there were to be many tests, speed of preparation was important. To accomplish these objectives, a special mechanized method was developed. The method which was finally selected is described in Appendix B and shown in Fig. 1. The prepared test plate is shown in Fig. 2.

Welding Equipment and Conditions

Welding equipment and conditions were held constant throughout this investigation. A 600-amp motor-generator power supply was used for most of the welding tests. A grooved copper plate with the groove protected with a coating of antispatter compound was used to back up the weld (shown in Fig. 3). The welding conditions used were those normally used for welding armor plate of this thickness. A circular, 60-deg-groove butt joint with electrode size, current, voltage and manual welding techniques suitable for $^1/_2$-in. thick armor were used. Current and voltages were recorded on automatic recorders. Standard manual welding equipment and procedures were used as prescribed in Specification MIL-W-12518. Root-pass welding current was approximately 180 amp at 25 v, and subsequent passes were 220 amp at 22 v. Figure 4 shows the setup of test plate, and the weld cross section is shown in Fig. 5.

Test Specimen

A test specimen similar to the Navy patch test for testing electrodes appeared to be suitable. A plate 12 x 12 in. was used as suggested by Levy and Kennedy[10] who found that, in a plate specimen less than 12 x 12 in., the restraint dropped off with decreasing size, while plates greater than 12 x 12 in. showed little increase in restraint. They also found that, in a constant-size plate, the restraint varied inversely with the patch diameter. In this investigation, the patch diameter was varied between 3 and $5^1/_2$ in. Variations in the patch diameter place the specimen under different degrees of restraint, which was used to give a relative indication of the plate's crack susceptibility.

Methods of Examining Circular-patch Test Plates

During welding and after completion of the welding, the top and bottom surfaces of the weld and plate were examined for surface cracks by a liquid-dye-penetrant test method (Specification MIL-R-11468). Any repair welds made were also checked by this method. After a specimen had been produced which showed no surface cracks, it was allowed to age for at least 48 hrs and then was tested by radiography with a sensitivity of 2% as specified in MIL-R-11468(ORD).

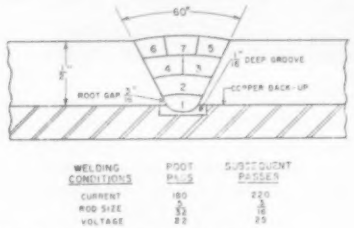

Fig. 5—Cross section of weld

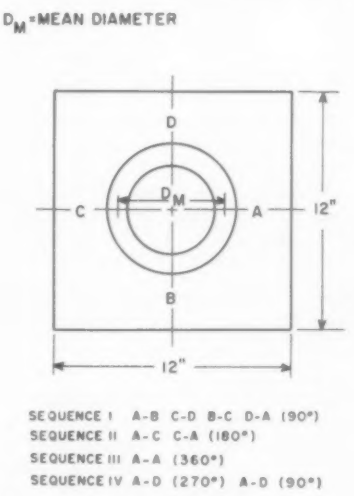

Fig. 6—Test plate showing different welding sequences

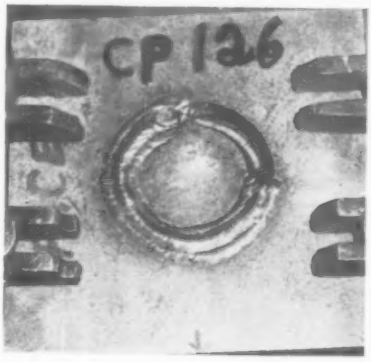

Fig. 7—Test plate after completion of first segment (Sequence IV)

Welding Tests

First Phase

Welding Sequence. Several exploratory tests were made using a circular bead-on-plate type weld similar to the underbead cracking test.[11] Cracking was not found for any diameter of test weld; so, this type of specimen was abandoned. A series of tests were made to determine the effect of welding sequence using a circular butt joint. Sequence I shown in Fig. 6 shows the welding in four 90-deg segments which is used in the Navy patch test. First, welding was completed from *A* to *B*. Next the segment from *C* to *D* was completed, then *B* to *C* and finally *D* to *A*. In sequence II, the first segment was 180-deg, started at *A* and stopped at *C*. After this segment was completed, the final 180-deg from *C* to *A* was welded. Sequence III was a full 360 deg. In this case, the starting point of each subsequent pass was advanced 90 deg to stagger the starting and stopping points. For sequence IV, the first segment was completed for 270 deg from *A* to *D*, and then the final 90 deg segment from *A* back to *D*. The electrode, preheat and interpass temperatures were held constant during this series. Test plate after completing the 270-deg sector (sequence IV) is shown in Fig. 7.

Electrode

The second series was made to determine the effect of electrode used for welding the circular patch. In this series, Grade 180 (90,000 tensile strength), Grade 230 (100,000 psi tensile strength), Grade 260 (120,000 psi tensile strength) and Special Alloy 103 (150,000 psi tensile strength) were used in the ferritic electrode class. In addition, an austenitic type 19–9 stainless-steel electrode (WL307) was used for one set of tests. Sequence, preheat and interpass temperature were held constant in this series.

Preheat and Interpass Temperature

An exploratory investigation was made of the effect of preheat and interpass temperature. The preheat temperature was taken as the temperature of the test plate just prior to depositing the first pass

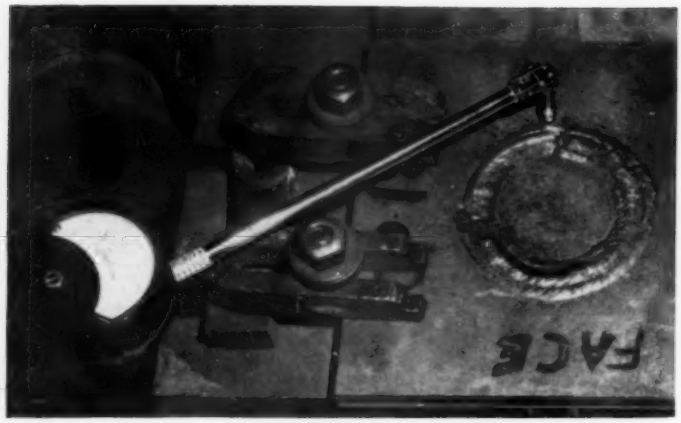

Fig. 8—Checking the interpass temperature of the test plate

of each sequence, and the interpass temperature was taken as the temperature of the plate prior to each subsequent weld pass. The following preheats were used: room temperature (80° F ± 5), 100, 212 and 300° F; and interpass temperatures were 100, 212 and 300° F. All tests in this series were made using the same sequence and the same type of electrode. Figure 8 shows the interpass - temperature determination during welding of the 90-deg segment of sequence IV.

Second Phase

From the first phase, the best sequence, electrode, preheat and interpass temperature were selected for the second phase. These selected conditions were applied to seven additional heats of armor. The only variables in the second phase were heat of armor plate and restraint.

Results and Discussion

First Phase

The results of varying the sequences are given in Table 2.

Table 2—Results by Varying Sequences

	Sequence	Results
I	Bead-on-plate, 360 deg	No cracks
II	Butt weld, 360 deg	Few cracks
III	Butt weld, 180 + 180 deg	Impractical
IV	Butt weld, 270 + 90 deg	Best results (cracked in small diameters)

The effect of different electrodes using sequence IV is given in Table 3.

Table 3—Electrodes for Circular-patch Test (with 270 + 90-Deg Sequence)

Grade	Tensile strength, psi	Results (plate cracking)
180	90,000	Little cracking
230	100,000	Little cracking
260	120,000	Cracked in small diameters
Alloy 03	150,000	Severe cracking
Stainless (19-9)	90,000	Weld cracking

The effect of different preheat and interpass temperatures is shown in Table 4.

Table 4—Effect of Preheat and Interpass Temperatures

Temperature (preheat and interpass),° F	Results
80 (Room temperature)	Impractical
100	Cracking in small diameters
212	Little cracking
300	Impractical

The effect of different circular-patch diameters (change in restraint) for the first phase using heat 0681, sequence IV, 100° F preheat and interpass is given in Table 5. From these results the test procedures were determined for the second phase.

Initial tests showed that a "bead on plate" was not sufficient to cause cracking. Welding sequence I was eliminated because of many segments in the test which made welding difficult; also, it was felt that the absence of starts and stops in a segment did not represent actual welding conditions. Sequence II was eliminated because of the mechanical difficulty of holding the patch in place while the first segment was put in. Sequence III in which the complete 360-deg segment was welded was not severe enough to crack the plate except in a few cases. Sequence IV appeared to give the best results. The 270-deg segment set up a restrained groove which was filled as the final 90-deg weld.

The stainless-steel electrode was eliminated because of cracking of the weld metal. The high-strength electrode (Alloy 103) apparently had a flow stress which was too high for the plate and caused severe plate cracking, while Grades 180 and 230 caused very little plate cracking. Grade 260 electrode caused cracking which increased with restraint and appeared to be the best electrode for the circular-patch test.

A preheat and interpass temperature of 300° F was impractical, as the high temperature was not easy to maintain and caused the operator difficulty in welding. A preheat and interpass temperature of 212° F gave scattered cracking but did not appear to produce conditions severe enough for the test. The 100° F preheat and interpass temperature gave the best results. Anything less than 100° F interpass was undesirable due to the long interval required for the plates to cool between passes. Several tests made using a 100° F interpass without the 100° F preheat showed that more severe cracking occurred when the preheat was omitted. Thus, to maintain consistent conditions for

Table 5—Effect of Circular-patch Diameters

	Diameter, in.					
Test	3	3½	4	4½	5	5½
1	X[a]	X	X	X	X	O
2	X	O	X	O	X	O
3	X	X	X	O	X	O
4	..	X	X	O	X	

[a] X = crack. O = no crack

Fig. 9—Bottom side of first segment showing crack under crater of first pass

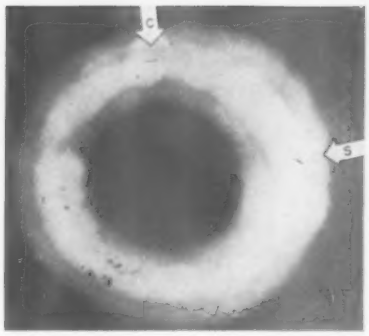

Fig. 10—Radiograph of circular patch 92. Arrow C shows crater crack; arrow S shows short crack

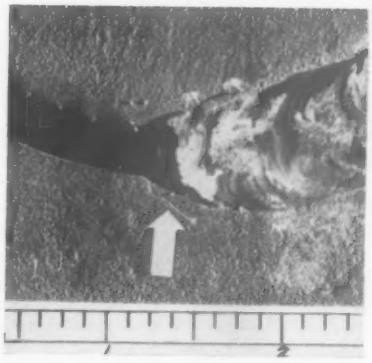

Fig. 11—Notch crack in plate at start of weld

each pass, a 100° F preheat and interpass temperature was standardized for the test. The results of the first phase indicated that conditions had been obtained which would give a test that could be easily made and which gave selected degrees of restraint. Results indicated that reproducibility was not as consistent as was desired, and the change in degree of cracking with decrease in patch size (increase in restraint) was not as consistent as had been anticipated. However, it was decided to continue the investigation applying these conditions to the other heats of armor.

Second Phase

From an analysis of the results of the first phase, conditions were selected for the second phase of the investigation. Conditions selected were: Sequence, 270 deg + 90, electrode-Grade 260 and interpass and preheat temperature 100° F. Complete details of test procedures are given in Appendix A. Seven additional heats of armor were prepared for testing with several different patch diameters in each heat. Welding conditions were held constant for the second phase. Some of the heats had limited tests due to short supply of plate.

The results of the second phase placed the heats in the following order of increasing crack susceptibility:

Heat JL 0724 (least crack susceptible)
Heat JL 0303
Heat JL 0823
Heat JL 0521
Heat JL 0681
Heat JL 0531
Heat JL 9191
Heat JL 0140 (most crack susceptible)

This order agrees with the known performance of these armor steels during fabrication of vehicles.

Upon completion of the second phase, it was apparent that the heat of armor selected for the first phase (heat 0681) was a borderline or below-average heat. A second factor to confuse the issue was the difficulty in selecting a suitable criterion for evaluating the radiographs.

As the final evaluation of the different circular-patch tests was to be from the radiographs of the test plates, the interpretation of the radiographs was very critical. Early evaluation was on a basis of the welded plate being free of cracks. Thus, any plate crack found in the radiograph indicated a failure. In some cases this was acceptable, but this criterion became difficult to use for evaluation when a few small cracks were encountered. The amount of cracking, such as length of crack or angle sustained by a crack, was used. Another factor to be considered was the cracks which developed during or after welding and which were repaired before the plate was radiographed. Further investigation into the cracking of the plate indicated that other methods of test evaluation should be investigated.

Types of Cracks Found

(*a*) *Weld Cracks.* Cracks in the weld metal were found by visual inspection, dye penetrant and radiograph. Typical weld-metal crack is shown in Fig. 9. As the test was designed to test the base plate, weld-metal cracks were not counted. In cases where the weld crack appeared to be severe enough to reduce the restraint on the base plate, the test specimen was discarded. Small crater cracks were not usually repaired. Weld-metal cracks as indicated by radiography are shown at *C* in Fig. 10.

(*b*) *Toe or Notch Cracks.* After completion of the root pass of the 270-deg segment, a condition of severe stress existed at the notches found at the start and end of the weld. Often a crack developed at these notches. Notch cracks as shown in Figs. 11 and 12 were usually about $^1/_2$ in. long in the heat-affected zone of the plate.

Dye - penetrant examination of both top and bottom of the weld and plate was made after the first weld pass. When notch cracks were detected they were chipped out and repaired.

(*c*) *Plate Cracks.* Cracks in the heat-affected zone of the plate are shown in Fig. 13. These cracks were found by radiography and were evaluated both on occurrence and total length of cracking for each specimen. Figure 14 shows the results of the first phase (heat 0681) when evaluated by different methods for different degrees of restraint.

Table 6—Results from Second-phase Tests

	Diameter, in.					
Heat	3	$3^1/_2$	4	$4^1/_2$	5	$5^1/_2$
0724	OOO[a]	...	OO	...	O	...
0303	...	XOX	OXO	OXOO	OOO	...
0823	OXO	...	...	OOX	...	...
0521	...	OXX	XXX	XXO	OXO	...
0681	XXX	XOXX	XXXX	XOOO	XXOX	XXO
0531	...	XX	OXXX	...	XXX	...
0191	...	XXX	XXX	XXX	OXX	...
0140	...	XXX	XXX	XXX	XXX	...

[a] X = cracks. O = no cracks

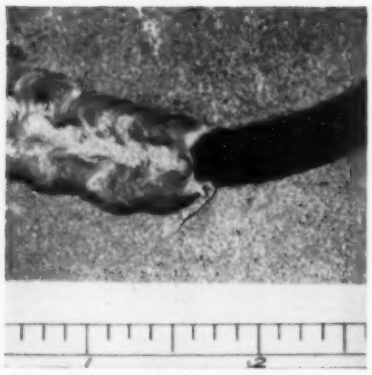

Fig. 12—Notch crack in plate at end of weld

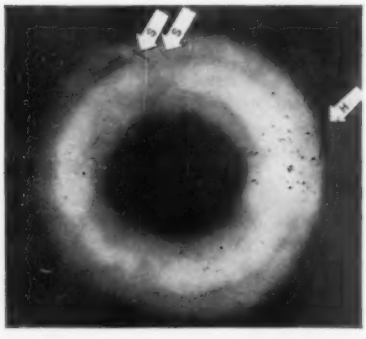

Fig. 13—Radiograph of circular patch 91. Arrow S shows short crack; arrow H shows heat-affected zone crack

Curve 1—Average number of plate cracks per test found in radiograph.

Curve 2—Average length of plate cracks per test found in radiograph.

Curve 3—Average number of notch cracks per test.

Curve 4—Percent of plates cracked.

The results from the second-phase tests of all eight heats on the basis of cracks (X) or no cracks (O) are given in Table 6. A careful study of these results shows a very poor relationship of degree of cracking to restraint.

A reassessment of the radiographs of the cracked plates revealed the cracks to be in two distinct classes. The most frequent type of crack was a small crack usually about $^1/_4$-in. long and at an angle of 45 deg to the centerline of the weld as shown at *S* in Figs. 10 and 13. These were usually near the start or finish of a segment of the weld. A cross section of this type of short crack is shown in Fig. 15. The macroexamination of this crack showed that it originated from a small slag inclusion—probably at the point of ignition of a new electrode (reinitiation of welding).

The second type of crack was a heat-affected zone crack parallel to the centerline of the weld. This type of crack was of varying length as shown in Fig. 13 at *H*, and is probably a propagation of a short crack discussed above. A cross section of this type of crack is shown in Fig. 16. Other similar cracks with their cross sections are shown in Figs. 17 and 18.

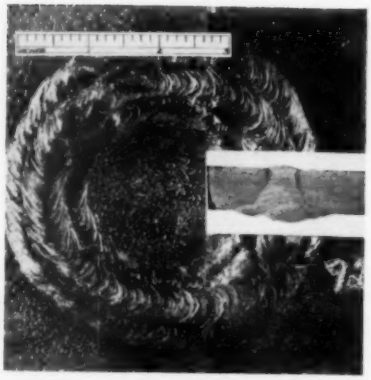

Fig. 15—Circular patch 92 showing cross section of short crack

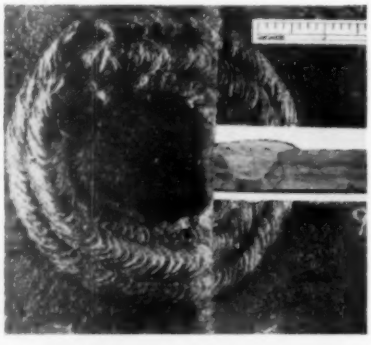

Fig. 16—Circular patch 91 showing cross section of heat-affected zone crack

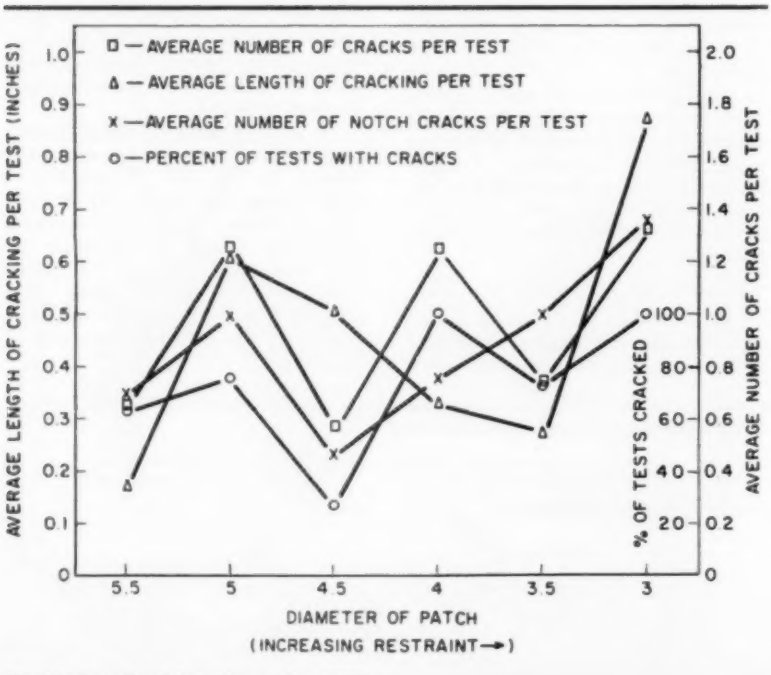

Fig. 14—Results of first phase—Heat 0681

In addition to the cracks shown in the radiographs, a tabulation was made of the "notch" cracks (Figs. 11 and 12) which had developed during welding and had been repaired.

The average length of cracking for all eight heats of armor made under the same conditions was broken down into types of cracks. A plot of these cracks, as effected by restraint, is shown in Fig. 19. The repaired notch cracks are almost constant over the range of test diameters. The cracks shown in the radiographs, both "short" and heat-affected zone cracks, increase with increasing restraint. Figure 20 shows a breakdown of the different heats showing heat-affected zone, short and average total inches of crack per test for all degrees of restraint. Curves for the individual heats show a similar trend. Generally, the curve for total crack length, short cracks and heat-

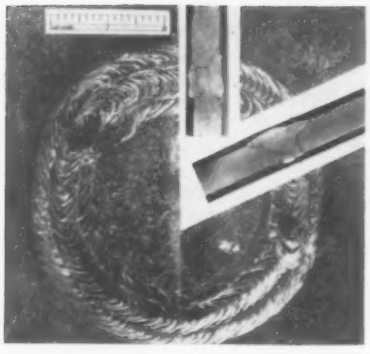

Fig. 17—Circular patch 46 showing cross section of heat-affected zone cracks

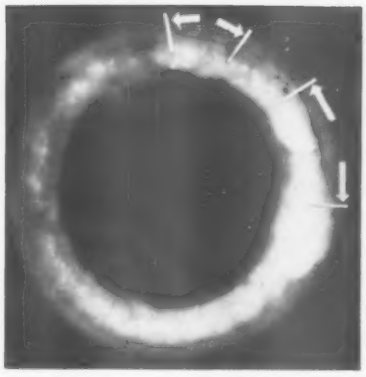

Fig. 18—Radiograph of circular patch 46 showing heat-affected zone cracks

affected zone cracks follow the same order. The repaired notch cracks are almost constant for all heats. Although the same number of tests and identical diameters were not used in each case, the tests were all in the same range, and the average length of cracks per circular patch was used. The results seem to be completely independent of the notch cracks which were repaired during welding, since they occurred with nearly equal frequency regardless of restraints or heat of material. Thus, for a test strictly for crack susceptibility, the notch cracks could be left in and counted. For a test specimen which would be further used for performance (ballistically or otherwise), the notch cracks could be repaired without affecting the evaluation. In Fig. 20 it can be seen that for the four heats which had heat-affected zone cracks, the degree of such cracking was about the same in each heat. The absence of any heat-affected zone cracks in four of the heats (three known to be good) and the heat-affected zone cracks in the other four (three known to be bad) may suggest that the presence of the heat-affected zone cracks in this test indicates crack susceptibility.

Summary

These tests show that, even when armor plate meets all the specifications, there can still be a wide variance in the way each individual heat will act when being welded. While this investigation is not extensive enough to determine all of the factors which affect the circular-patch test, it does indicate that a test procedure has been obtained which will evaluate different heats of armor steel according to their susceptibility to cracking when welded under varying degrees of restraint.

It must be realized that in a weldability test, crack-susceptibility is only one part of weldability, and its evaluation applies only to the fabricating conditions imposed. In this investigation the conditions were limited to multipass, manual, butt welds in Army armor. The armor may or may not indicate the same degree of susceptibility to weld cracking if a different condition, such as a single-pass fillet or automatic welding, etc., is used.

It can be concluded that the circular-patch test, as described here, will determine the relative crack susceptibility of different heats of Army armor for multipass butt welds.

Recommendations

In order to prove the value of a test such as this, it is necessary to apply the test on a semiproductive-type basis. Therefore, it is recommended that:

(*a*) Through the cooperation of a fabricator, several plates of armor be obtained covering high, medium and low crack susceptibility heats. These plates could be tested by the circular-patch test and the results compared with the fabrication history of the heat.

(*b*) Through the cooperation of a steel producer, one plate be obtained from each heat of armor produced and be subjected to the circular-patch test to predict its crack sus-

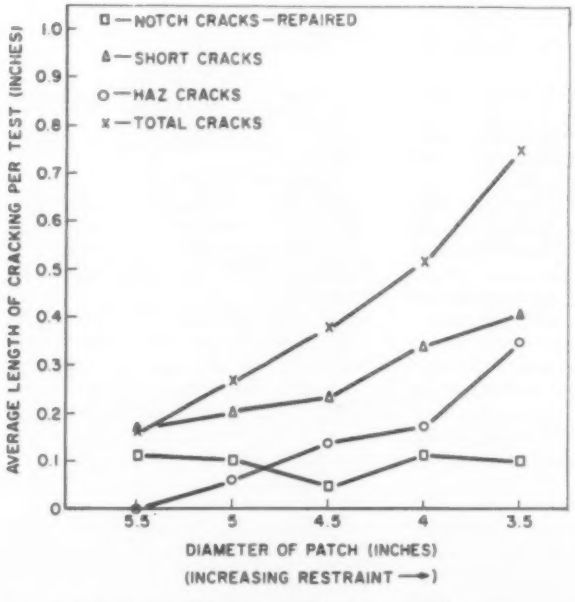

Fig. 19—Average cracking vs. restraint for all eight heats of armor

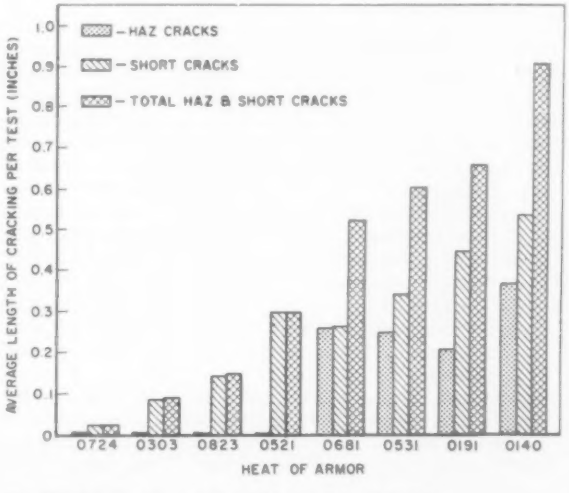

Fig. 20—Types of cracks found in each heat for all patch diameters

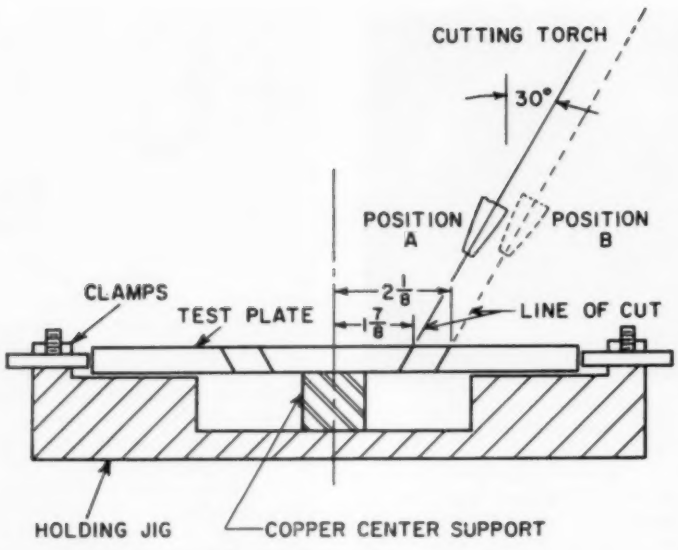

Fig. 21—Turntable setup for test-plate preparation

ceptibility. A comparison of this prediction with subsequent fabrication history would establish the accuracy of the test.

(*c*) The product of this test, the 12 x 12-in. plate with the circular-butt weld, be adapted as a test to determine the second part of a weldability test—performance under service conditions. For example, the plate could be subjected to a ballistic or drop-weight impact test at different temperatures.

APPENDIX A

Circular-patch Test Procedure

The standard test shall consist of 3 test plates made in each of the following mean diameters: $3^1/_2$, $4^1/_2$ and $5^1/_2$ in., using the following welding procedure.

Welding Procedure

The following steps are necessary to produce a circular-patch specimen:

1. Preparation of plate
   (*a*) Oxygen cut specimen (see Appendix B).
   (*b*) Grind cut surface, removing oxide and rough edge.
   (*c*) Coat copper backing plate with antispatter compound (Fig. 3).
   (*d*) Position plate and patch on backing plate and clamp down (Fig. 4).
2. Preheat plate and fixture and allow to cool to 100° F before start of weld.
3. Weld root pass of 270-deg segment.

Conditions

   (*a*) Current, 175–185 amp DCRP.
   (*b*) Voltage, approximately 19–21 v.
   (*c*) Rod size, $^5/_{32}$ in., Grade 260 (E12015).
   (*d*) Preheat to 100° F ± 5°.
   (*e*) Start weld at 3 o'clock and weld to 12 o'clock (or any equivalent 270-deg segment), using normal welding techniques.
4. Subsequent passes until 270-deg segment is completed (Fig. 7).
   (*a*) Current 220–230 amp DCRP.
   (*b*) Voltage 21–23v (approx.).
   (*c*) Rod size $^3/_{16}$ in., Grade 260 (E12015).
   (*d*) Interpass temperature 100° F ± 5°.
5. Remove plate from fixture, clean both sides, examine with dye penetrant.
6. Repair any cracks by chipping, grinding and rewelding.
7. Replace in fixture (without center clamp).
8. Weld final 90-deg segment (from 3 o'clock back to 12) (Fig. 8).
   (*a*) Root pass—same as 3 above (including preheat).
   (*b*) Subsequent passes—same as 4 above.
9. Total passes about 7 for $^1/_2$-in. plate or 9 for $^5/_8$-in. plate (Fig. 5).
10. Remove from fixture, clean and examine. Chip and repair any cracks found.
11. After 48 hr, radiograph as directed in MIL-R-11468 (ORD). Conditions used in this investigation were:
   (*a*) 400 kv at 5 ma.
   (*b*) 40-in. focus-film distance.
   (*c*) Fine grain film.
   (*d*) 0.005-in. lead screen.
   (*e*) One minute, 25-sec exposure (sensitivity as determined by a penetrameter at least 2% or better).
12. Evaluation of Radiograph.

Observe cracks as shown in the radiograph and classify into "short" and "heat-affected zone" cracks. Measure length of cracks and plot average length for each heat. Compare heats as shown in Fig. 20.

APPENDIX B

Preparation of the Test Plate

Although any method of preparing the test specimen is satisfactory, the following procedure was found to be most efficient:

(*a*) Turntable setup as in Fig. 1 with a variable speed control, a clamping device to hold 12 x 12-in. plate ($\pm^1/_8$ in.), and a cutting torch with an adjustment for angle of cut and an adjustment for the in-and-out movement. Center of plate is supported by a copper bar.

(*b*) With plate centered and stops set, torch is started midway between position A and position B (shown in Fig. 21 for 4-in. circular patch). When plate is cut through, move to position A, start turntable and inside cut is made. Torch moved to position B and outside cut is made (table may be stopped if necessary.

(*c*) Normal cutting conditions used: Oxygen, 100 psi; acetylene, 4 psi; speed (approx.), 15 ipm; tip, No. 2.

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Prestrain, Size and Residual Stress in Static Brittle-Fracture Initiation

Paper by C. Mylonas appeared in October 1959 issue of Welding Journal Research Supplement, 414-s to 424-s

Discussion

By G. M. Boyd

This paper further develops the theme of previous papers with which the author has been associated, to the effect that the role commonly attributed to residual stress (in the initiation of brittle fractures) is in reality played by "exhaustion of ductility."

This theme, broadly speaking, is fully supported by the present writer, who has for many years urged that the metallurgical effects which invariably accompany residual stresses should be more fully investigated. This point was made explicitly in a paper[1] published in 1954. The point was made even more forcibly in the final report[2] of the Weld Stress Committee of the Welding Research Council (USA) in which the beneficial effects of stress-relief heat treatment were attributed, not to the removal of stresses, but to the "improvement in metallurgical structure."

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As the author points out, there has been much confusion of thought due to the usual coexistance of residual stress and metallurgical change. It was well established by Weck[3] that residual stresses cannot occur without plastic flow, which in itself induces "exhaustion of ductility," which is a metallurgical change. Moreover, plastic flow, in association with time and heat (such as that which is inseparable from welding) produces strain-age embrittlement in most structural steels. Thus, the mechanical concept of residual stress is inextricably bound up with metallurgical changes.

The author, however, emphasizes only one of these metallurgical changes, namely the exhaustion of ductility due to plastic strain, and although it is mentioned in the paper, comparatively little attention is given to strain-age embrittlement, which may be an even more important factor in service fracturing.

The author has placed clear and timely emphasis on the importance of a proper understanding of these matters, in order to bring about a more judicious use of stress relieving, and to "distinguish the danger and restore the ductility in embrittled areas free from residual stress." This point cannot be too strongly emphasized. Merely to remove the stresses goes only part way toward the safety envisaged.

The author's remarks about the inadequacies of the "Griffith-type" theories are also endorsed by the present writer, with the reservation that the energy-balance approach can be very fruitful if some of these inadequacies are removed. This aspect has been discussed in two recent papers.[4, 5]

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Disscussion

By A. M. Freudenthal

The test results presented and discussed in this paper are of considerable interest. It seems, however, that the rather excessive claims put forward of having achieved "really brittle" static fractures in the laboratory for the first time "ever," as well as of having discovered the only "rational" explanation of the phenomenon in terms of the "exhaustion of ductility" are in no relation to the actual results achieved.

It has been known for a long time that the result of the imposition of highly nonuniform compressive prestrain is cracking on release of the force or moment producing such prestrain. It is also well known that yielding at the maximally stressed fiber in a nonhomogeneous stress field with sharp gradients starts at a stress considerably above the yield-stress in uniaxial tension, which might thus easily cause nonductile fracture with limited crack-length instead of yielding. The neglect of the effect of stress gradients in the theory of isotropic plasticity or work-hardening is only justified in the absence of very steep stress gradients.

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The "exhaustion of ductility" concept which implies the existence of a unique limit of energy dissipation by plastic deformation as a fracture criterion has been so frequently proposed and so frequently disproved in the last 50 years that it would seem hardly believable that it should be dragged out again.

The presented results are consistently and simply explainable on the basis of the highly nonhomogeneous tensile residual-stress fields enforced by compressive prestrain close to the root of the notch. It is obvious that the ductility, in terms of the ratio of yield stress to fracture stress in tension, is a significant parameter in so far as in a notched plate with a high ratio the cracking may even start "spontaneously," a phenomenon that is quite frequently observed at the inside of the bends of hooks of concrete reinforcing bars of certain steels, while lower ratios require the super imposition of a tensile force on the residual-stress field to cause cracking. The intensity of this force depends mainly on the intensity of the residual-stress field, and it is therefore obvious that it can be made any percentage of the force required to produce fracture in the plate without prestrain.

Discussion

By L. J. Larson

This paper is very interesting and the results are a valuable contribution to the solution of the brittle-fracture problem. The author is to be complimented for developing a new procedure and type of specimen for producing low-stress brittle fracture without the use of welding. This eliminates the effect of weld metal in a study of the brittle fracture problem.

The author concludes that the exhaustion of ductility is the important factor in the brittle fracture problem and that residual stress is of little or no importance. This is diametrically opposite to the conclusion of many other investigators who have worked on this problem and who believe that the presence of residual stress is one of the necessary conditions for low-stress brittle fracture.

Since the purpose of this investigation was to develop a theory and an explanation of the initiation and propagation of brittle fracture rather than to investigate the effects of various pre- and post-treatments of welded structures, it becomes important to test the author's theory by applying it to the results obtained by the author as well as other investigators, particularly Wells[1] and Kennedy[2] of England and Kihara and Masubuchi[3] of Japan.

For convenience, we may summarize the prior history and condition of the material at the notch at the time of testing at low temperature for each of several series of tests.

1. The Author's Principal Series of Tests

The material at the notch had been severely deformed and work-hardened, first in compression and then, to a lesser degree, in tension by release of the load.

The stress at the root of the notch was at the yield point in tension.

Specimens failed by brittle fracture at stresses generally well below the yield point of the material when tested at low temperatures.

2. British Wide-plate Tests— As-welded

The material at the notch had been plastically deformed and work-hardened due to repeated heating and cooling during welding.

The stress at the root of the notch was at yield point in tension.

Specimens failed by brittle fracture at comparatively low stresses when tested at low temperatures.

3. British Wide-plate Tests— Thermally Stress Relieved al 650° C.

The material at notch had been work hardened by welding the same as specimens of Group 2, but later softened by thermal stress relieving.

The stress at root of notch was low.

Specimens did not fail by brittle fracture but developed yield point strength at −56° C.

4. British Wide-plate Tests— Heated Locally to About 650° C.

Material at root of notch work-hardened during welding but softened again by local heat treatment.

The tension stress at the root of the notch was high, probably yield-point value due to cooling after local heating.

Specimens failed at practically zero stress at a temperature of about −8°C. These specimens were weaker than most as-welded specimens.

5. The British Wide-plate Tests— Mechanically Stress Relieved

The material at the notch had been work hardened by welding the same as specimens for Group 2. After welding, these specimens were prestressed in tension to a stress slightly in excess of the yield point of the material at a temperature above the transition temperature for the steel. The material at the notch was thus stretched plastically in addition to the work hardening which occurred during the welding operation.

The stress at the root of the notch was probably compressive when the specimen was subjected to the low-temperature test.

The specimen did not fail by low-stress brittle fracture but developed yield-point strength at −50° C.

The Japanese investigators have duplicated many of the tests reported by the British and the results of the Japanese tests are in general agreement with the British results. For many of the tests made in Japan,[3] the saw-cut notch in the specimen was made after the welding was completed. The results of tests with this type of notch appear to agree with those in which the notch was made before welding, indicating that the plastic deformation at the root of the notch normally caused by welding is not essential to produce brittle failure.

The Japanese also made tests on specimens which had been prestressed in tension to various loads and then tested at low temperatures. All these specimens developed low-temperature strengths which were equal to or greater than the stress to which they had been prestressed.

In Table 3, the author gives results of tests on specimens which had been prestressed in tension following the precompression. He cites these data as evidence that tensile prestressing does not prevent brittle fracture. However, it will be noted that all of these specimens failed at stresses above the tensile prestress. This is in agreement with the results obtained by the Japanese investigators. Had the author increased the tensile prestress to the yield point strength of the material, it is probable that brittle failure would have been eliminated as in the case of the mechanically stress-relieved specimens reported by the English and Japanese.

In a paper[4] submitted to Commission X of IIW, the Japanese report the effect of stress relieving at various temperatures below 650° C. They found that the strength at low temperature decreased as the stress-relieving temperature decreased. This appears reasonable since, at the lower temperature, only a partial stress relief is obtained.

The author observes that even though residual stresses may possibly have some effect on the load at failure, this effect would be so small as to be negligible since residual stresses act on such a small proportion of the material. From an examination of the test results presented by the British and Japanese investigators, it appears that this effect is far from negligible. Stress relieving increased the low-temperature strength from only a few thousand pounds per square inch to the yield point strength of the material. In actual practice this would be a

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very significant increase since it would be the difference between a disastrous failure at stresses below the designed values and a successful design which would develop the yield-point strength of the structure.

Based on the results obtained by the various investigators, we may test the validity of the two proposed theories of brittle failure, namely: (1) that brittle failure is due to the exhaustion of the ductility of the material at the root of the notch, and (2) that brittle fracture is due to residual tensile stresses at the root of the notch in combination with other factors.

First, consider the theory that failure is due to the exhaustion of ductility. The author's series of tests on precompressed specimens and the tests on the as-welded wide-plate specimens both appear to satisfy this theory. In both cases, the metal at the root of the notch was severely deformed and embrittled and, as the theory would indicate, brittle failure occurred during the test at low temperature. The results of the tests of the thermally stress-relieved wide-plate specimen are also in agreement with the theory. After welding, the ductility of the material at the root of the notch was restored by the thermal heat treatment and so, brittle failure did not occur. The welded-plate specimen which was heated locally to the stress-relieving temperature and then allowed to cool does not support the theory. The ductility at the root of the notch was restored by the local heating and no further embrittlement occurred unless it is assumed that the stresses caused by local cooling introduced some embrittlement. Specimens treated in this manner should not have failed in a brittle manner but they actually did fail at low loads. All specimens subjected to tension after precompression or welding show an improvement in strength at low temperature. This is contrary to what may be expected since the additional cold working following the compression or welding should cause additional work hardening and embrittlement. The author explains this behavior on the basis of some unknown anisotropic work hardening and aging law. It is difficult to see why plastically stretching the material should eliminate the harmful effects of plastically compressing it.

We may now examine the test results in the light of the theory that brittle failure is due to residual tensile stresses at the notch or crack. All specimens which are known to have high residual tension at the notch such as the author's precompressed specimens, the as-welded plate specimens and the welded-plate specimen which was heated locally to 650° C, failed by brittle fracture and are thus in agreement with the theory. Specimens which were stress relieved either thermally or mechanically did not develop brittle failure at temperatures down to −50° C or lower, again in agreement with the theory. Specimens which were partially stress relieved either mechanically or thermally showed improved strength at low temperature and the improvement was in proportion to the amount of stress relieving on the specimen. Thus all of the test results reported by the author and by the English and Japanese investigators are explained by the theory that brittle failure is dependent upon the state of residual stress.

It, therefore, appears that the author's tests are a further confirmation of residual-stress theory. From this viewpoint, the results presented by the author are very valuable since they eliminate the effect of a variable chemical composition and metallurgical structure which are inevitable in a welded specimen.

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Author's Closure

The contributions of Messrs. G. M. Boyd, A. M. Freudenthal and L. J. Larson are gratefully acknowledged. Their experience and opinions are universally respected and their remarks are of great help as they complete the views presented in the paper, or they indicate the points needing a clearer explanation.

Mr. Boyd's discussion gives considerable support to the opinions expressed in the paper, and his references to his own and other British publications are welcome additions to those given in the paper.

The importance of strain aging is by no means minimized in the paper. Strain aging is included in the comprehensive term "strain history," which covers the previous type, magnitude and variations of strain, the length of time of application and since the application of the load, the temperature during and after straining, etc. All the precompressed plates were fully aged. The importance of strain aging is being studied in detail with special tests using uniformly precompressed bars with various strain histories.

Agreement also exists on the inadequacy of the energy criteria. The author, however, does not share Mr. Boyd's optimism on the removal of the inadequacy in the specific problem of the static initiation of fracture. Energy criteria are necessary but not sufficient conditions governing phenomena involving a start or a nucleation. An additional criterion is needed, perhaps a stress or a combined stress and strain criterion.

Professor Freudenthal does not think that the systematic reproduction of fractures under static loading and at low net applied stress presents any novelty. However, the picture derived from the great number of tests spurred by the catastrophic failures of ships during the war and extending over a period of more than ten years, is quite different. The object of these tests was to reproduce and study the phenomenon of brittle fracture under static conditions of loading, but as a rule, in all tests, irrespective of size, temperature and depth of notches, the fracture of sound steel was preceded by general yielding of the cross section. No initiation of low net static-stress fracture could be obtained, and resort was made to the artificial means of starting a fracture by cooling to liquid-nitrogen temperature and also applying explosive impact. The relation of

average net fracture stress to brittleness of fracture was indicated by Wells, who was among the first to produce low static-stress fractures of notched and welded steel plates. Such controlled fractures of unwelded steel, free of the metallurgical effects of welding, is generally accepted to have been achieved at Brown University by the use of suitable prestraining. Professor Freudenthal suggests that fracture following intensive precompression was known. However, the basic phenomenon involved was not considered as an important cause responsible for the low-stress brittle initiation of fracture in structures. The author will feel satisfied if the view is now accepted that an exhaustion of ductility, such as results at the precompressed notches, or in the notched welded plates of Wells, is a fundamental cause in the brittle initiation of fracture in steel. Professor Freudenthal makes an unwilling injustice with his accusations. On careful scrutiny he will be unable to find any passage claiming the discovery of exhaustion of ductility or uniqueness of explanation of brittle fracture. He will find many acknowledgments and references to similar ideas.

The concept of exhaustion of ductility under certain conditions (e.g., "under the stresses and constraint of the notch"), but not necessarily under others, is fundamental in this approach to the problem of fracture initiation, but is frequently misunderstood. It was derived on the basis of the evidence presented in the paper and receives a striking confirmation from further tests carried out at the National Physical Laboratory in England,* and at Brown University.† It was found that uniformly precompressed steel subsequently tested in tension in the same direction may fracture in an exceedingly brittle manner at very low and uniform strain and at room temperature. The test bars were cylindrical without notches or any residual stresses. But tension tests of bars taken at right angles to the precompression showed an increased ductility beyond that of the virgin material. The strong anisotropy of the exhaustion of ductility following prestraining cannot be doubted.

In an as yet unsolved problem like the one of brittle fracture, all views are being considered. Those of Professor Freudenthal are particularly respected. However, it is felt that these views cannot be reconciled with all the experimental evidence contained in the paper. In particular, an explanation of fracture relying on residual stress cannot be reconciled with the lack of early cracks or of low-stress fractures of the plates with residual stresses but no compressive prestrain at the notches. It is clear that localized residual stresses alone are not the answer to the problem of brittle fracture initiation. Residual and applied stresses do not add algebraically once yielding is reached at the root of the notch. The argument against localized residual stresses is completed by the recent tests in which brittle fracture was obtained in the absence of residual stresses or gradients, but with highly precompressed steel. These tests prove unambiguously the reality and the fundamental importance of the anisotropic exhaustion of ductility. The two sets of experiments: (*a*) residual stresses—no prestrain and (*b*) prestrain—no residual stresses, were specifically designed so as to differentiate between the relative importance of the two usually coexisting factors. An explanation of the problem of the static initiation of brittle fracture must be able to account for these results. Considerations of available vs. required ductility in combination with the phenomenon of anisotropic exhaustion of ductility do offer a systematic, though as yet qualitative, approach to these questions, as well as to the other aspects of brittle fracture initiation already discussed. Other approaches compatible with the experimental evidence are not excluded.

The remarks on Professor Freudenthal's contribution apply to a great extent also to Mr. Larson's. In addition it should be said that none of the examples offered by Mr. Larson gives a clear separation of the two causes, i.e., exhaustion of ductility and residual stresses. This frequent coexistence of causes and their simultaneous modification in possibly opposite ways is the reason of so much confusion on the real cause of the *static initiation* of brittle fracture. The only tests scientifically designed for the separation of the two causes are those described in the paper which drew the discussions (Fig. 9, and page 421-s, column 1), which are not taken under consideration by Mr. Larson, and the later tests with uniformly precompressed steel free of residual stresses mentioned in the footnotes of the present closure. Mr. Larson has an excellent understanding of the problem and realizes the importance and consequences of an anisotropic exhaustion of ductility, which, however, he considers improbable. In the light of the colossal directional variation of the properties of precompressed steel, the anisotropic exhaustion of ductility can no longer be doubted or ignored. It is then quite clear that compressive and extensive prestrain can and do have considerably different influence on the remaining ductility.

It should always be remembered that residual stresses are wiped out by plastic deformation of the order of 0.001, and when this happens they are not present at the time of fracture. Of course they may not be wiped out, as in the instance of large fields of reaction stresses in conjunction with stress raisers, or may certainly be wiped out, as, e.g., when they are highly localized. The picture of the contest between available and required ductility is fundamental in assessing the causes of fracture. This principle, together with the still incompletely well-known laws of anisotropic exhaustion of ductility, is the first step in the long and difficult road leading to the quantitative determination of the meaning of a "localized" and a "large" region of residual stress, and to the precise assessment of the dangers of fracture.

* J. H. Rendal, Discussion presented at the Conference on Brittle Fracture, Cambridge, England, Sept. 28–30, 1959. See also: N. P. Allen, 11th Hatfield Lecture, *J. Iron & Steel Inst.*, **191**, 1958.

† D. C. Drucker, C. Mylonas and G. Lianis. "On the Exhaustion of Ductility of E-Steel in Tension Following Compressive Prestrain," WELDING JOURNAL, **39**, (3), Research Supplement, 117-s to 120-s (1960). Also: C. Mylonas, "Exhaustion of Ductility as a Fundamental Condition for Static Brittle Fracture Initiation," Discussion presented at the Conference on Brittle Fracture, Cambridge England, Sept. 28–30, 1959.

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